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INDIVIDUALIZED SCIENCE INSTRUCTIONAL SYSTEM

Eye & Vision

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INDIVIDUALIZED SCIENCE INSTRUCTIONAL SYSTEM

Eye & Vision

Ginn and Company

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FOREWORD

Evidence has been mounting that something is missing from secondary science teaching. More and more, students are rejecting science courses and turning to subjects that they consider to be more practical or significant. Numerous high school science teachers have concluded that what they are now teaching is appropriate for only a limited number of their students.

As their concern has mounted, many science teachers have tried to find instructional materials that encompass more appropriate content and that allow them to work individually with students who have different needs and talents. For the most part, this search has been frustrating because presently such materials are difficult, if not impossible, to find.

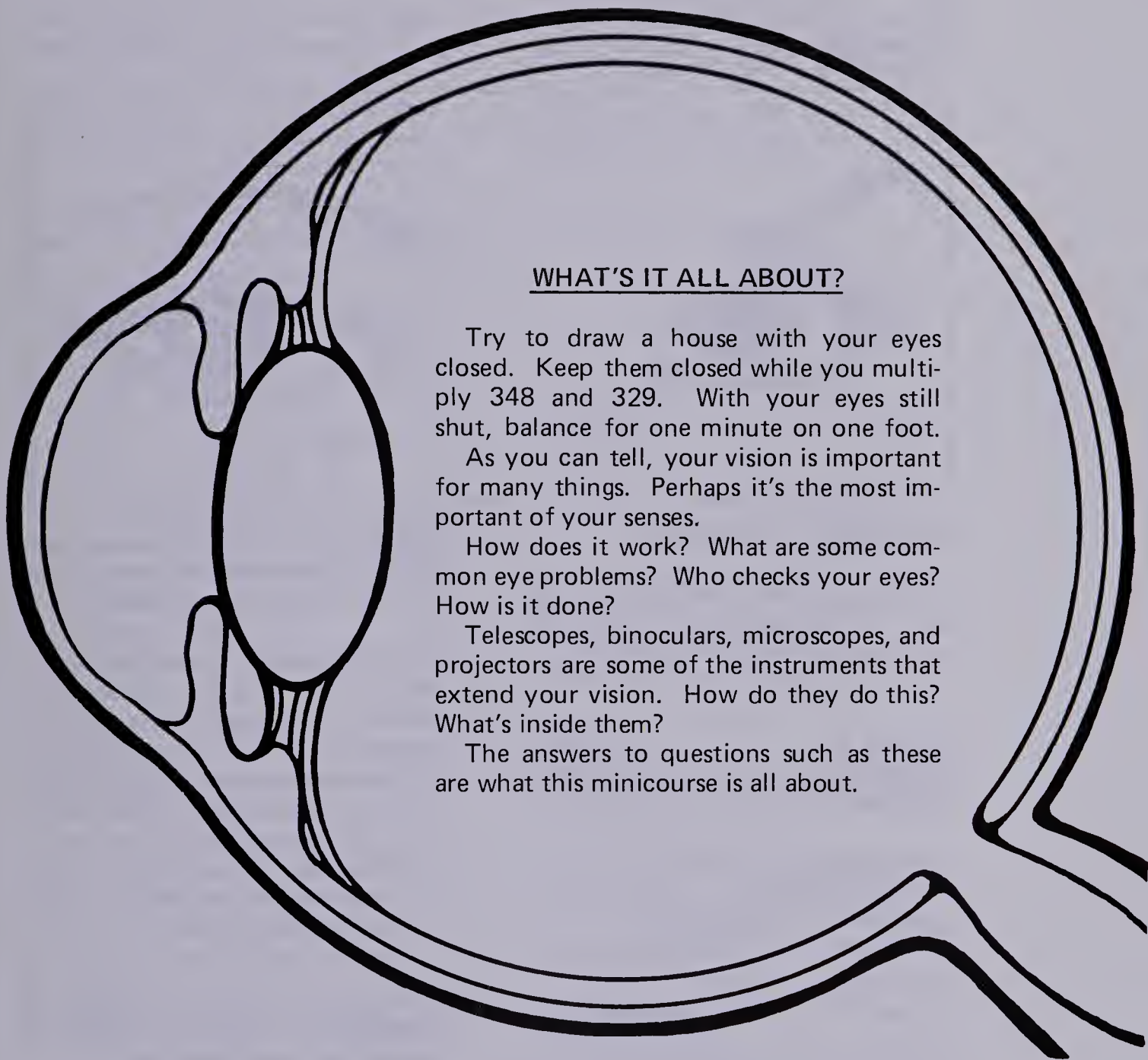
The Individualized Science Instructional System (ISIS) project was organized to produce an alternative for those teachers who are dissatisfied with current secondary science textbooks. Consequently, the content of the ISIS materials is unconventional as is the individualized teaching method that is built into them. In contrast with many current science texts which aim to “cover science,” ISIS has tried to be selective and to limit our coverage to the topics that we judge will be most useful to today’s students.

Obviously the needs and problems of individual schools and students vary widely. To accommodate the differences, ISIS decided against producing tightly structured, pre-sequenced textbooks. Instead, we are generating short, self-contained modules that cover a wide range of topics. The modules can be clustered into many types of courses, and we hope that teachers and administrators will utilize this flexibility to tailor-make curricula that are responsive to local needs and conditions.

ISIS is a cooperative effort involving many individuals and agencies. More than 75 scientists and educators have helped to generate the materials, and hundreds of teachers and thousands of students have been involved in the project’s nationwide testing program. All of the ISIS endeavors have been supported by generous grants from the National Science Foundation. We hope that ISIS users will conclude that these large investments of time, money, and effort have been worthwhile.

Ernest Burkman
ISIS Project
Tallahassee, Florida

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WHAT'S IT ALL ABOUT?

Try to draw a house with your eyes closed. Keep them closed while you multiply 348 and 329. With your eyes still shut, balance for one minute on one foot.

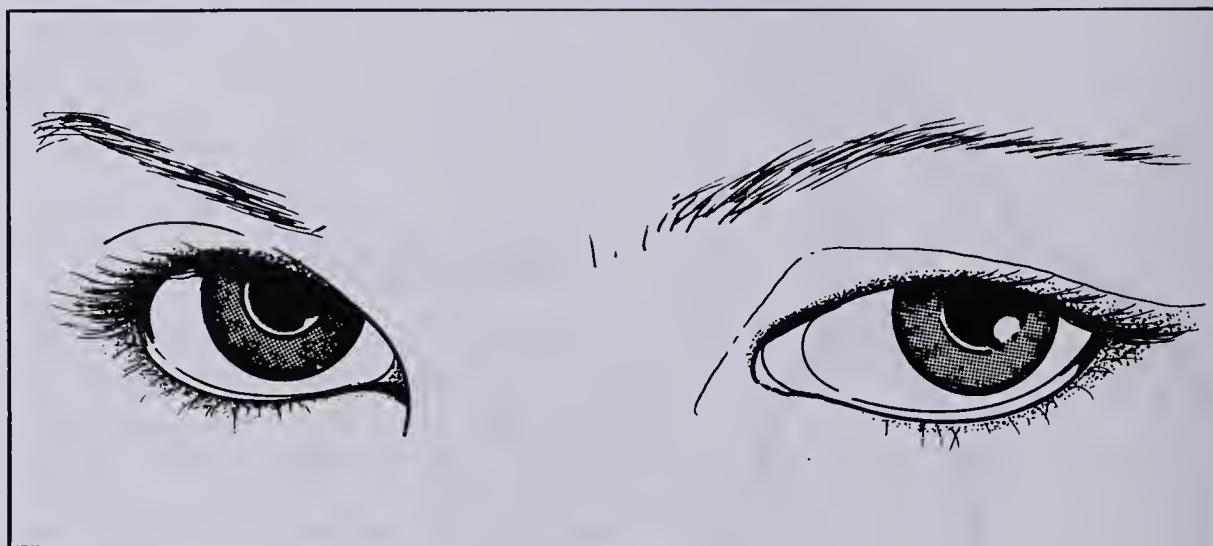
As you can tell, your vision is important for many things. Perhaps it's the most important of your senses.

How does it work? What are some common eye problems? Who checks your eyes? How is it done?

Telescopes, binoculars, microscopes, and projectors are some of the instruments that extend your vision. How do they do this? What's inside them?

The answers to questions such as these are what this minicourse is all about.

Core



ACTIVITY 1: PLANNING

If you plan to do Activity 2, do it right after you do this activity. The other activities may be done in any order.

Activity 2

Page 5

Objective 2-1: Describe the main parts of the human eye.

Sample Question: Match the part of the eye with its description.

<u>Eye Part</u>	<u>Description</u>
A. Iris	1. a transparent covering
B. Vitreous humor	2. contains colored pigment
C. Pupil	3. changes its shape
D. Cornea	4. a hole
E. Lens	5. fills the inside of the rear part of the eye

Objective 2-2: Distinguish between observations of light phenomena and models or theories to explain light phenomena.

Sample Question: You are 100 metres away from the start of a footrace. The starter pulls the trigger on the gun. For each of the following statements, write *O* if it's an observation. Write *T* if it's a theory or a model.

- A. You see the smoke from the gun before you hear the report.
- B. Light from the gun travels to your eyes in the form of rays.

Activity 3

Page 13

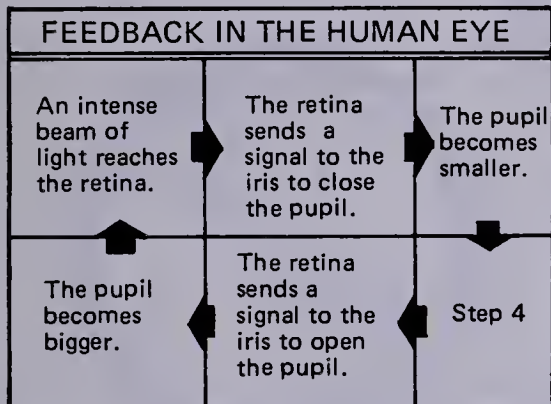
Objective 3-1: Describe the functions of the main parts of the human eye.

Sample Question: What is the function of the iris?

- A. It focuses light on the retina.
- B. It produces tears and keeps the eyes moist.
- C. It helps control the amount of light entering the eye.
- D. It's the place where the optic nerve enters the eye.

Objective 3-2: Describe how feedback controls pupil size as light changes.

Sample Question: In the following feedback diagram, Step 4 is missing. Which item below the diagram should be Step 4?



- A. The iris starts to flutter.
- B. The pupil darkens.
- C. The pupil gets larger.
- D. Less light reaches the retina.

Activity 4 Page 18

Objective 4-1: Describe how the lens focuses light on the retina.

Sample Question: What happens to the lens of your eye when it is focusing?

- A. It moves forward and back.
- B. It gets more curved and less curved.
- C. It does both A and B above.
- D. It doesn't change shape or position.

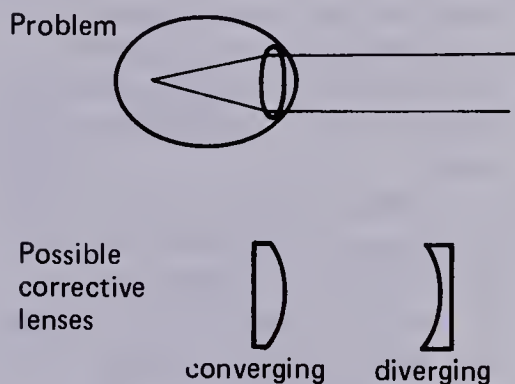
Objective 4-2: Describe the causes and effects of nearsightedness, farsightedness, and astigmatism.

Sample Question: A nearsighted person is one who

- A. can't see well up close.
- B. has trouble seeing at a distance.
- C. has an irregular cornea.
- D. can see well at a distance.

Objective 4-3: Describe how eyeglasses correct nearsightedness and farsightedness.

Sample Question: What eye problem is shown in the following diagram? Which lens might help correct it?



- A. Farsightedness, diverging
- B. Nearsightedness, diverging
- C. Farsightedness, converging
- D. Nearsightedness, converging

Activity 5 Page 27

Objective 5-1: Describe the four parts of an eye examination.

Sample Question: Suppose your vision tested as 20/40 according to an eye chart.

- A. You have 20 vision in one eye and 40 vision in the other.
- B. You can see only 20/40ths of what you should.
- C. You can see something better at 40 metres than most people can at 20 metres.
- D. You were barely able to read something that a person with normal vision can read from twice as far away.

Answers: 2-1. A2, B5, C4, D1, E3;
 2-2. AO, BT; 3-1. C; 3-2. D; 4-1. B;
 4-2. B; 4-3. B; 5-1. D

Objective 5-2: Identify the professionals who can prescribe lenses, and describe the procedures used.

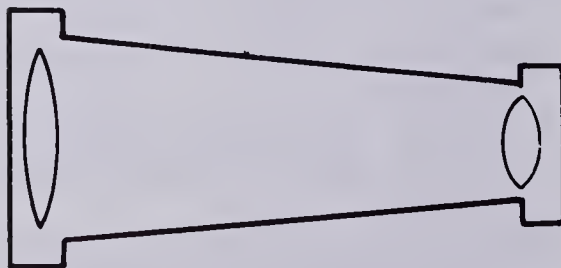
Sample Question: Which method would an optometrist use to prescribe glasses?

- A. Check and recheck what the patient could see with various lenses, while getting feedback from the patient.
- B. Use a Snellen chart, and prescribe according to which line the patient reads best.
- C. Try various glasses on the patient, selecting those with which the patient could read all of the Snellen chart.
- D. Try various glasses on the patient, and allow the patient to choose the most comfortable pair.

Activity 6 Page 34

Objective 6-1: Describe the types of images seen by users of telescopes, microscopes, and projectors.

Sample Question: An observer looks through a refracting telescope like that shown below, with the distance between the lenses about equal to the sum of the focal lengths. What would the observer see?

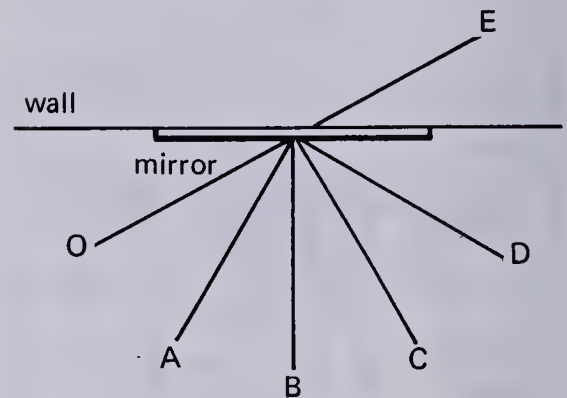


- A. An image that is right side up
- B. An image that is upside down
- C. A mirror image
- D. No image at all

Activity 7

Page 42

Objective 7-1: Explain how mirrors form images and how devices that use mirrors work.

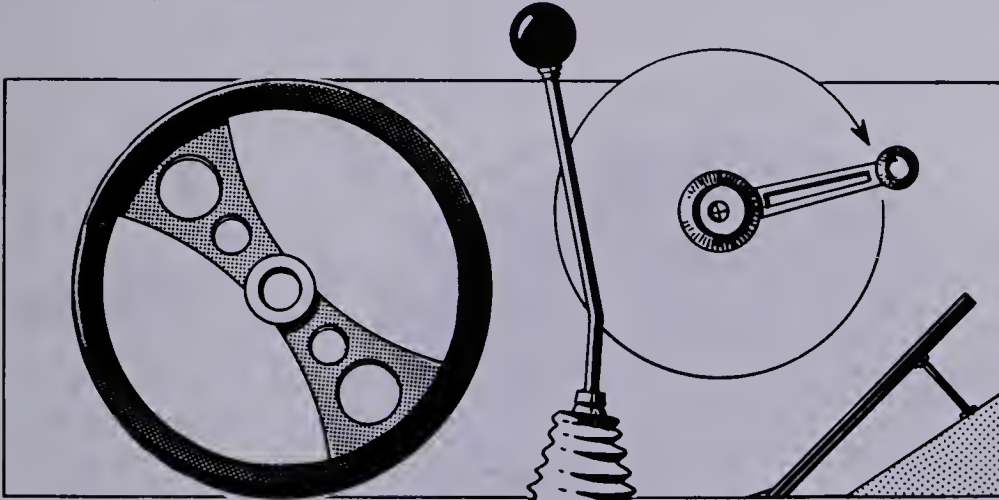


Sample Question: Look at the diagram above. An observer stands at O looking into a mirror hanging on a solid wall. At what position should you stand — A, B, C, D, or E — to look into the observer's eyes in the mirror?

Answers: 5-2. A; 6-1. B; 7-1. D

ACTIVITY 2: MEET THE EYE

You couldn't drive a car if you didn't know a steering wheel from a gas pedal or a gear shift from a window crank. When you're learning about a thing, it's usually important to know about its parts.



You'll be learning about the eye. You need to know something about the parts of an eye before you can understand how an eye works.

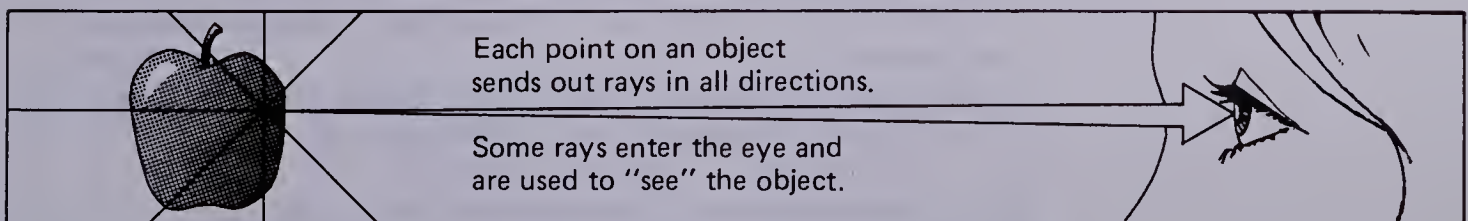
Eyes use light to see objects. So you need to have a way of thinking about light in order to understand seeing.

One way to think about seeing is to use a model or theory for light. A model or theory is different from an observation of something. When you observe something, you use your senses to learn how it behaves. When you use a model or theory, you invent a reason for its behavior.

One particular light model says that light travels from one point to another in fine lines called *rays*. No one has ever seen a single light ray. But the model is a handy concept to use in talking about light and tracing its path.

★ 2-1. People speak of a ray of light going from one point to another. Are they making an observation or using a model?

In seeing, light has to travel from what is seen (the object) to the eye. Light usually travels in a straight line from the object to the eye.



- 2-2. Do all the rays from an object enter the eye?

Now look at Figure 2-1 below. It shows a top view of a right eye.

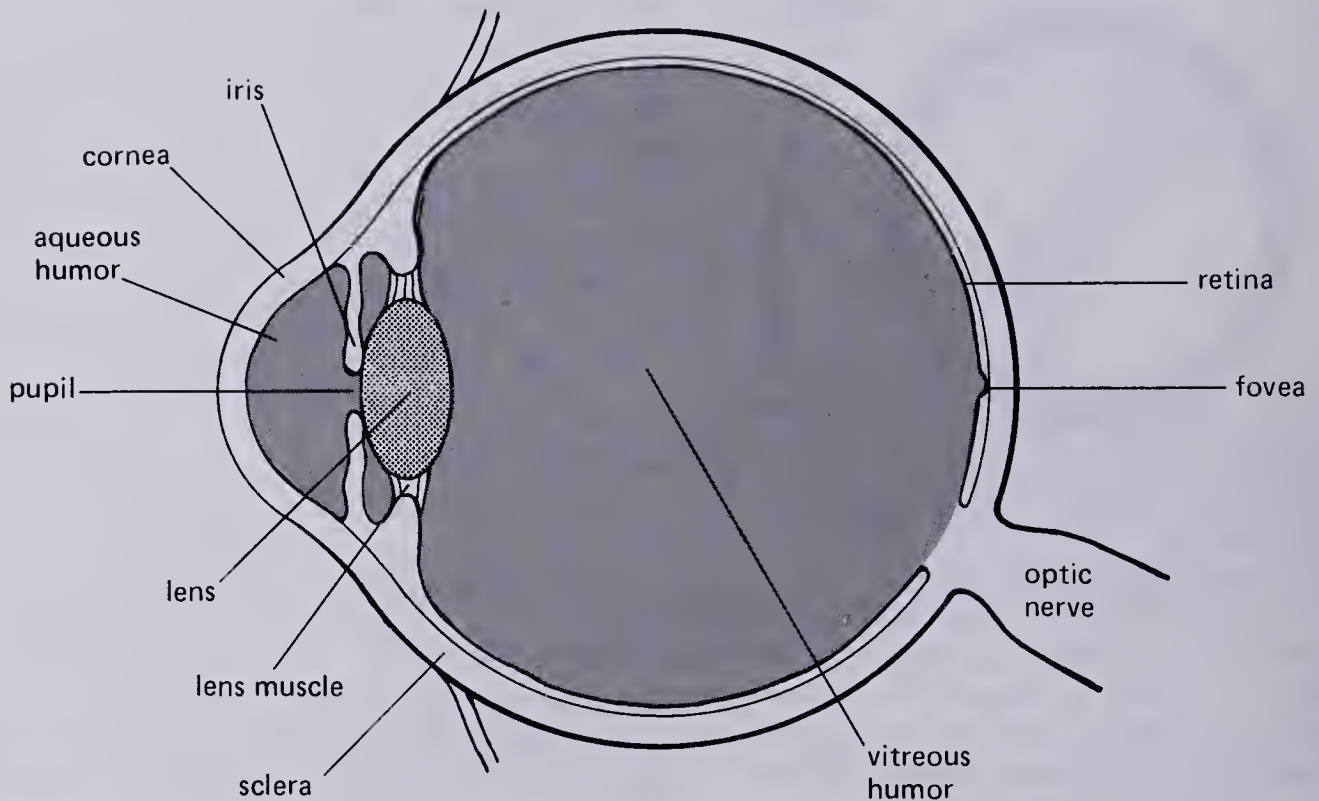


Figure 2-1

- 2-3. Suppose a ray of light came from the left and entered the eye. Name the parts shown in Figure 2-1 above that the light would have to pass through before striking the retina.

Light passes through five parts. Here they are in order.

The *cornea* [KORE-nee-a] is a tough, transparent membrane covering the front of the eye.

The *aqueous humor* [A-kwee-us HUE-mer] is a watery fluid between the cornea and the lens.

The *pupil* is a round hole in the center of the iris.

The *lens* is a transparent body, whose shape is changed by the *lens muscle*.

The *vitreous humor* [VIH-tree-us HUE-mer] is a transparent jelly filling the interior of the back of the eye.

- ★ 2-4. How does the pupil differ from the other parts?

Note that the pupil is a hole in the center of the iris. The iris is the colored, circular area that widens and contracts to control the size of the pupil. It also gives the eyes their color.

Surrounding the colored iris is the sclera [SKLER-a]. That's the "white of the eye" you've heard about. It's a tough, white, protective covering that connects to the cornea.

ALL RIGHT, MEN,
DON'T FIRE 'TIL
YOU SEE THEIR
SCLERA!



- 2-5. What is the difference in appearance between the sclera and the cornea.

The retina covers about two-thirds of the eye's inside surface. When light strikes the retina, the actual process of vision begins. In the middle of the retina is the fovea. This is a small spot of the sharpest vision. The optic nerve, which leads to the brain, is attached slightly to one side.

- 2-6. What fills the inside of the eye and is in contact with the retina?

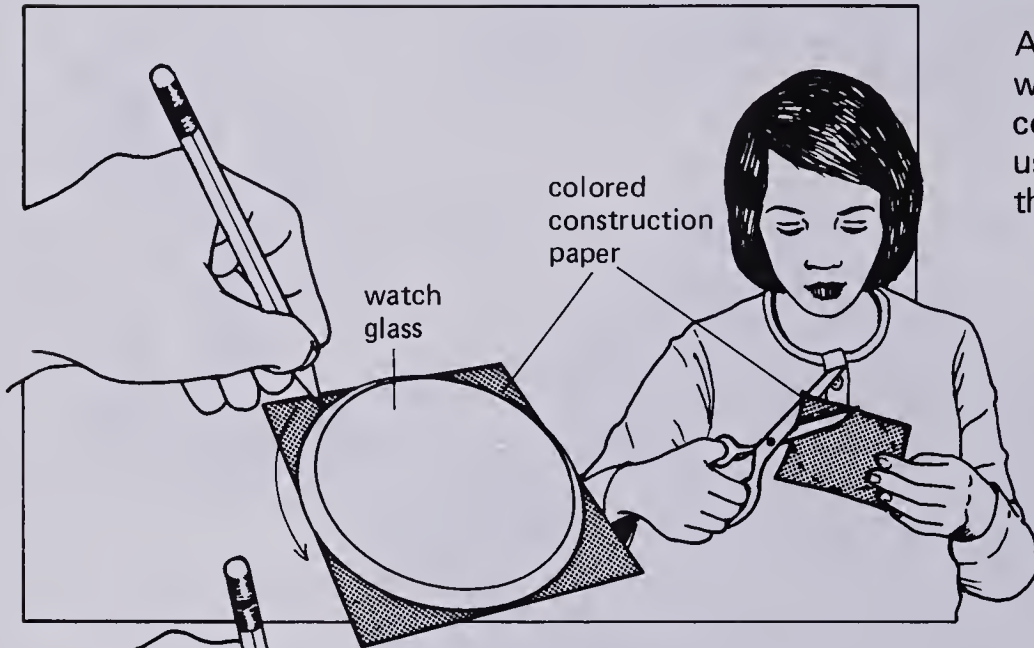
An eye model can help you learn those parts. If one has already been put together, you can use it now. Turn to the middle of page 10. Otherwise, you will need the following materials.

convex lens, 15-cm focal length
watch glass or petri dish cover, 9 to 10 cm in diameter
piece of colored construction paper, 10 cm X 10 cm
piece of white cardboard, at least 21.5 cm X 28 cm
small spherical balloon
piece of white paper
transparent tape
ruler or metre stick
drawing compass
scissors

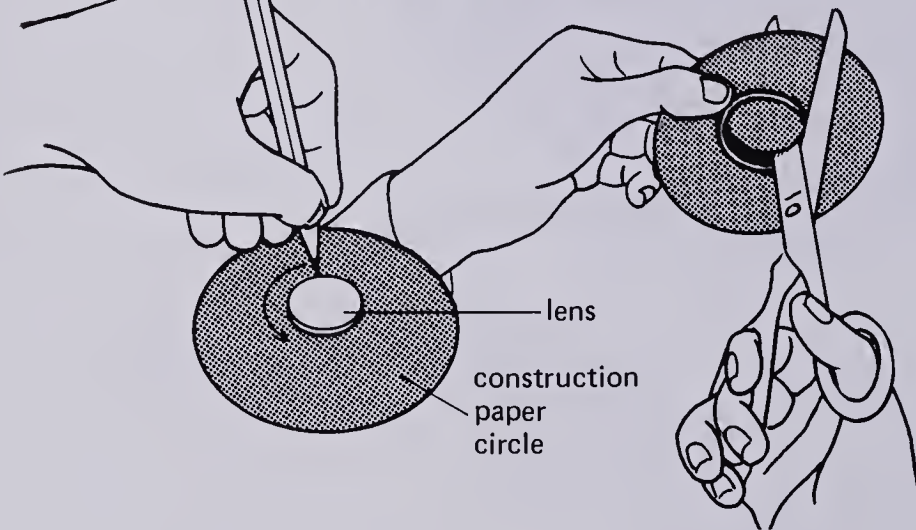
CAUTION

Use care in handling the lens. It can scratch or break. Clean it with soft tissues only.

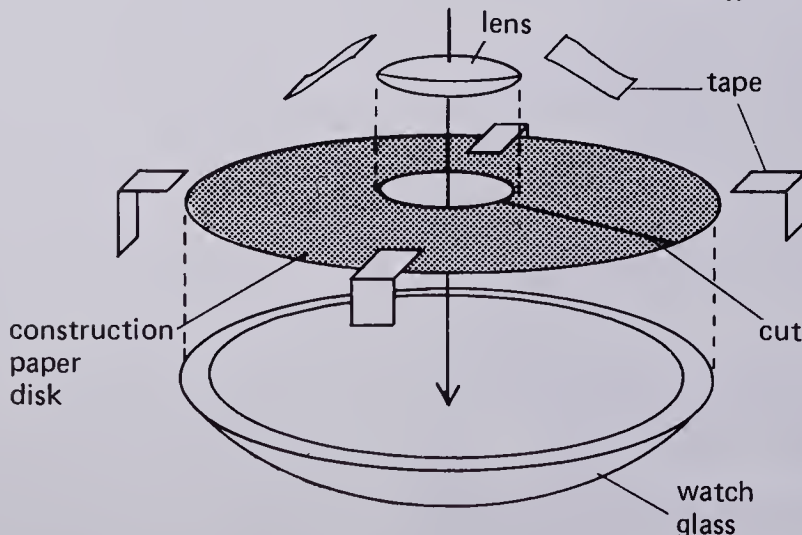
If you need help with the metric measurements, do "Resource Unit 9: Measuring Length" before going on.



A. Trace the outline of the watch glass on the colored construction paper. Then use the scissors to cut out the circle that you traced.

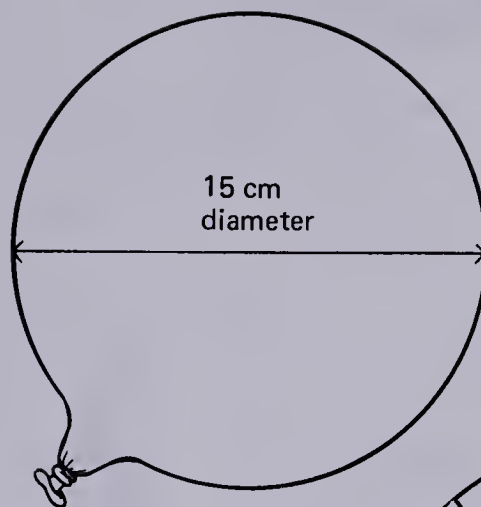


B. Position the lens in the exact center of the paper circle. Then trace around it. Cut out this circle a little smaller than you traced it.

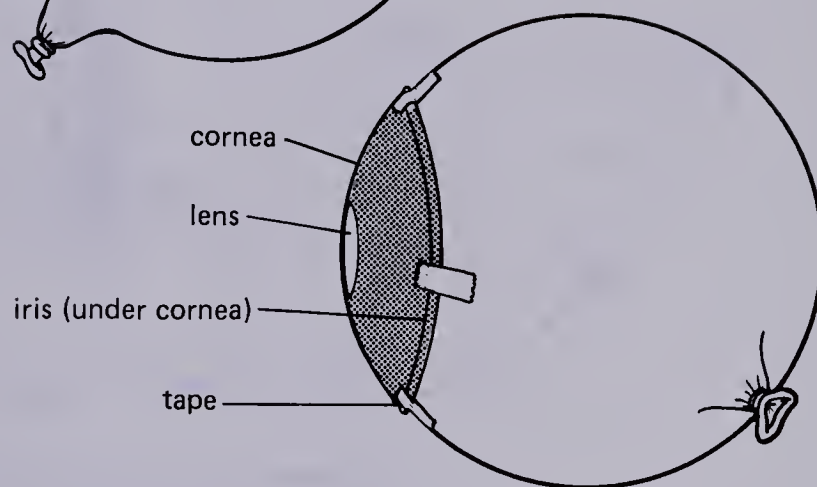


C. Make a single cut halfway across the paper disk, as shown. This will allow it to lie flat inside the watch glass. Then use tape to fasten it on the watch glass. After it is securely fastened, tape the lens over the hole. The tape should just hold the lens on the edges. Don't put tape across the center of the lens.

D. Blow up the balloon so that it is 15 cm in diameter. When it is about that size, tie a knot in the neck. The balloon represents the eyeball, and the neck represents the optic nerve.



E. The watch glass—lens assembly represents the cornea (watch glass), the iris (paper disk), and the lens of the eye. Tape it to the balloon. It should be on the opposite side from the knotted neck, but not directly opposite.

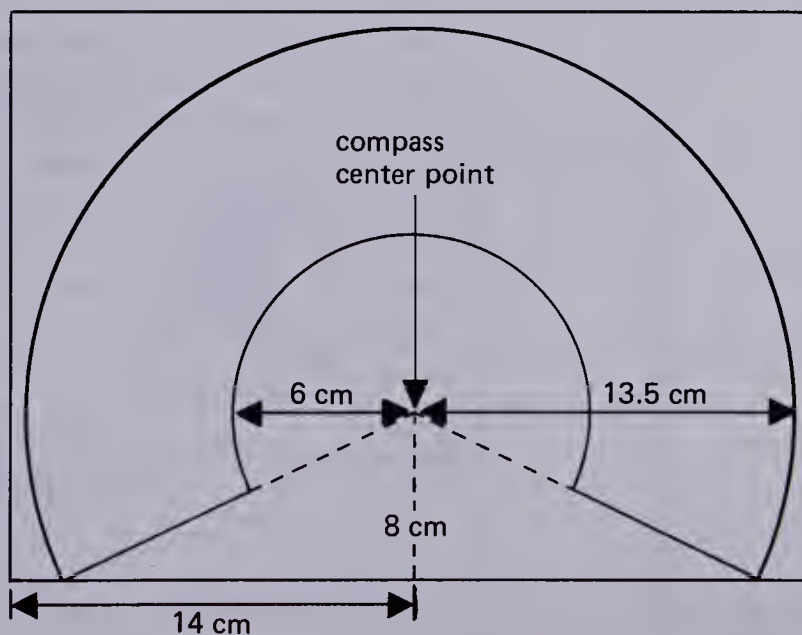


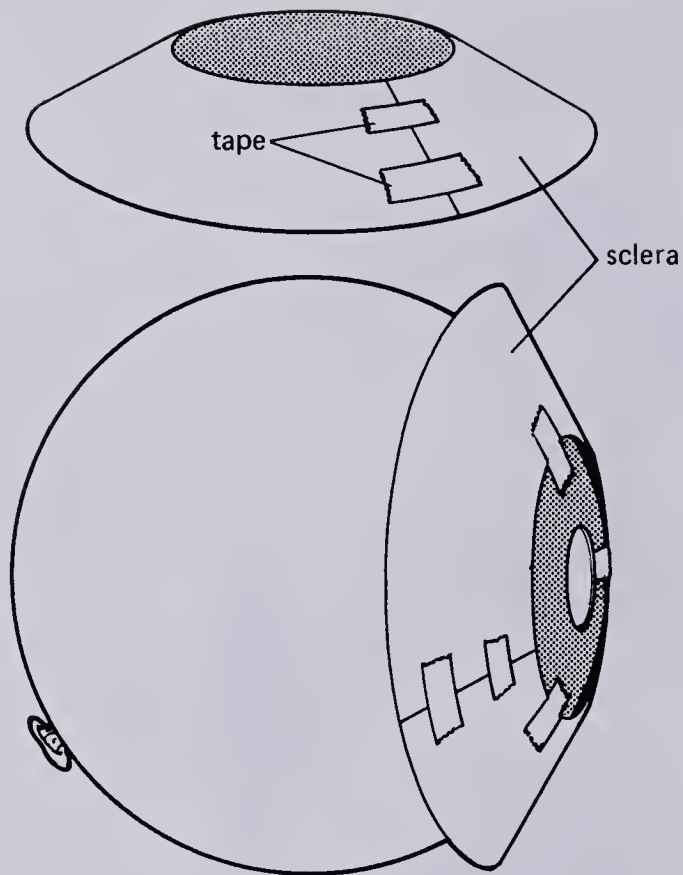
● 2-7. Where should the cornea (watch glass) be in relation to the lens?

F. Now prepare the sclera. First get the piece of white cardboard. Measure across 14 cm and then up 8 cm. This gives you the center point for the compass.

G. From this compass center point, draw one arc with a 13.5 cm radius and a second arc with a 6 cm radius. Connect the two arcs with straight lines from the points where the larger arc hits the edge, in toward the center point.

28 cm X 21.5 cm white cardboard





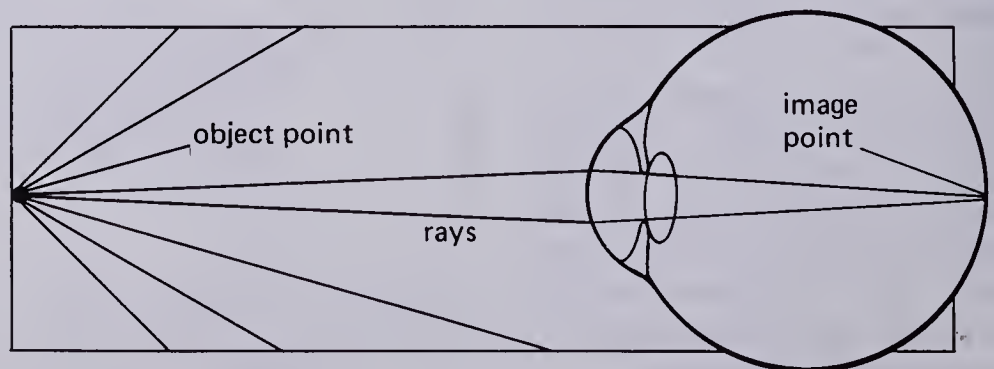
H. Using the scissors, cut out the large C formed by the lines. Then tape the straight ends of the cardboard together to make a cutoff cone.

I. Fasten the sclera (cardboard cone) to the cornea (watch glass) with small pieces of tape. Your model eye is now complete.

Before trying to work with the model eye, let's look more closely at the ray model for light.

Assume that an object is lighted in some way — that is, it's not in darkness. Then light rays are going out from every point on it. And these rays are going out in every direction from each point.

Rays from one point on the object pass through different places on the lens. If the model eye is to "see" the object accurately, these different rays have to converge (get back together). A well-made lens allows the rays to converge. It changes the directions of the various rays passing through it. It changes them just enough so they will converge at a point called the *image point*.



Remember that rays are going out from each and every point on the object. For each of these object points, there will be a matching image point where the rays come back together. The set of image points then make up an image of the object. This is called a *real image* if the rays really converge. For clear vision, the real image must strike the retina.

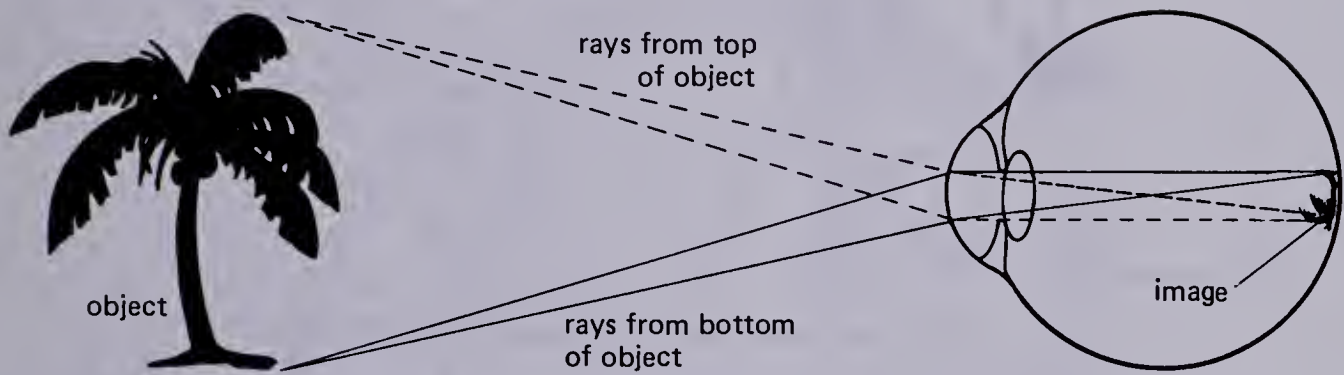


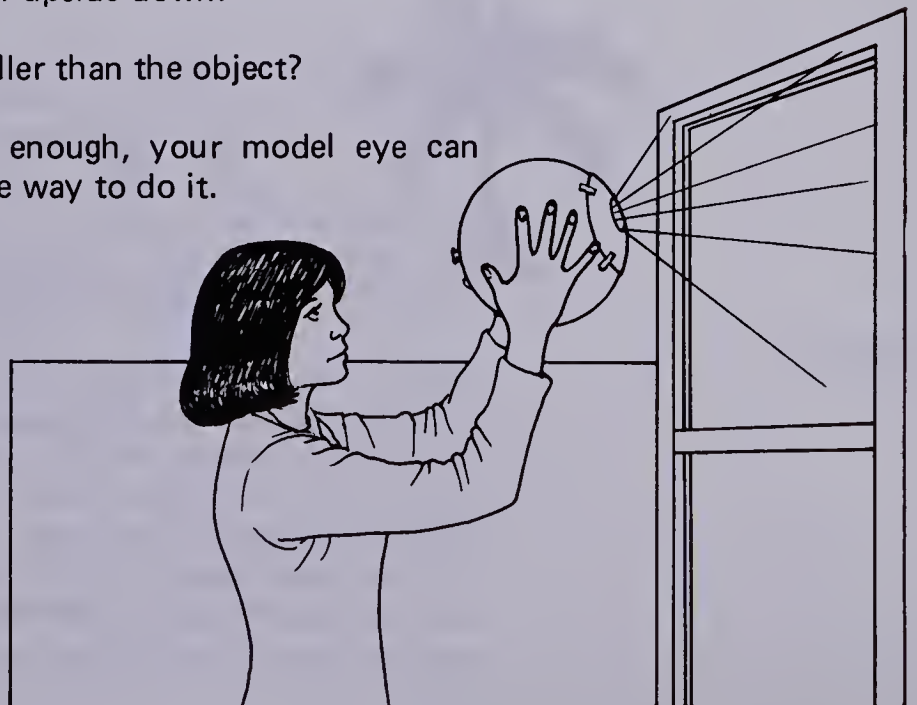
Figure 2-2

Look carefully at the object and image in Figure 2-2 above. Then answer the next three questions.

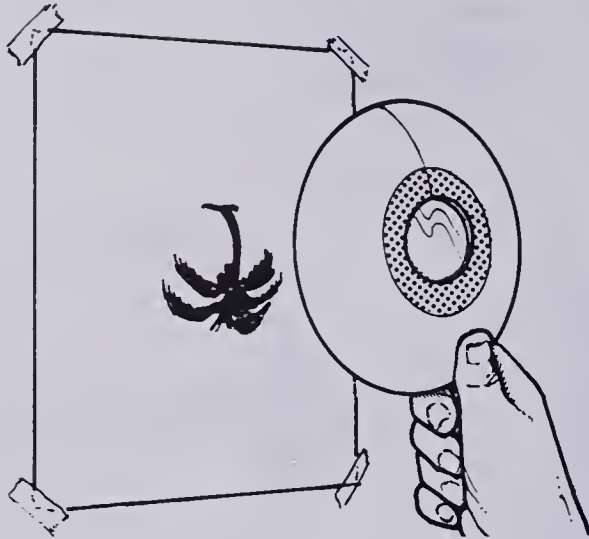
- 2-8. Do the rays really converge in the back of the eye (on the retina)?
- 2-9. Is the image right side up or upside down?
- 2-10. Is the image larger or smaller than the object?

If the balloon is transparent enough, your model eye can actually form an image. Here's the way to do it.

A. Hold the model eye facing toward a window or a brightly lit object. Look at the balloon's surface opposite the lens. This is where the image should appear.



If your model eye didn't form an image, you can look at it another way. Here's how.



B. Remove the sclera (cardboard), cornea (watch glass), and lens from the balloon. Fasten a piece of white paper on the wall opposite a window or bright object. Hold the cardboard so that the lens is about 15 cm from the white paper.

● 2-11. Is the image right side up or upside down?

★ 2-12. In an actual eye, on what surface does the image form?

You may have been surprised that the image was upside down. After all, you don't see things that way with your eyes. The reason for this is that the signals from the eye are turned right side up by the brain. Look at Figure 2-3 below.

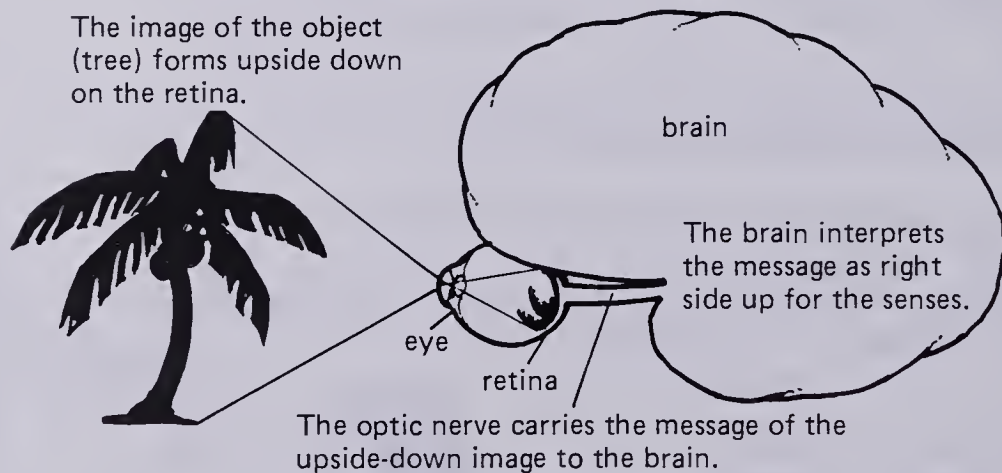


Figure 2-3

Of course, your model is just a representation of the eye. It doesn't have the watery aqueous humor behind the cornea, nor the jellylike vitreous humor inside. It also lacks muscles and other structures. But it does show some of the important parts of that wonderful sense organ — the eye.

You made a model eye in this activity. Just as important, you made a mental model — the ray model for light. Both will help you understand the behavior of light and how light helps you to see.

ACTIVITY 3: A JOB FOR EVERY PART

The eye is an instrument that collects light from an object and forms an image on its rear surface — the retina. To do this, all parts of the eye must work together. In Activity 2, you learned the names of the parts of the eye. Now take a look at what the parts are supposed to do. Study Figure 3-1 below.

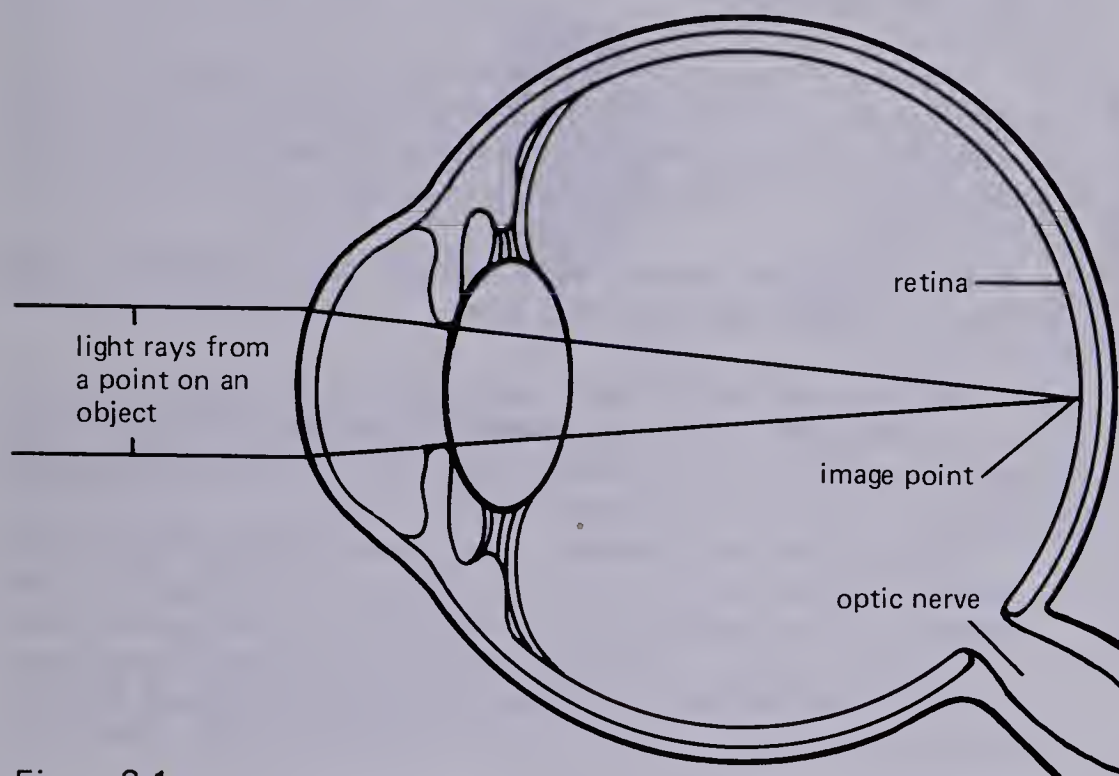


Figure 3-1

- 3-1. What are the four parts, not counting the pupil, that light must pass through before reaching the retina? (If you had trouble with the names of the parts, review Activity 2.)

When an image of an object is formed on the retina, the light from the object is said to be *focused*. The lines in Figure 3-1 above represent the path that light rays from an object might take in order to focus on the retina.

To form an image, most of the light rays must bend or change direction. Figure 3-1 shows this bending taking place when the rays pass through the different parts of the eye.

Each of the four parts you named in Question 3-1 helps form the image on the retina. But the parts have other jobs too. Think back to the model of the eye in Activity 2. (You might want to look at the model again to refresh your memory.)

- 3-2. What part of the model protects the lens?

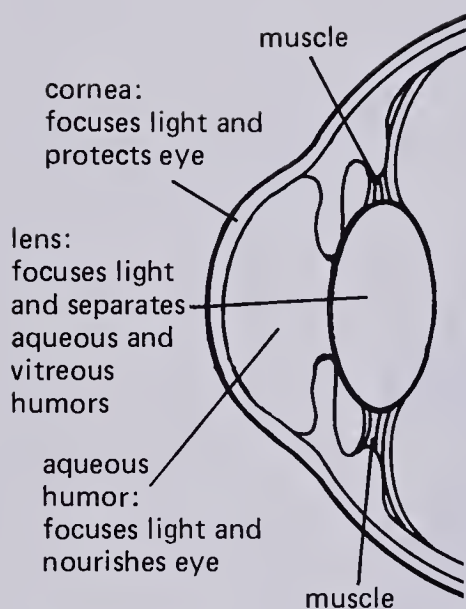


Figure 3-2

In the same way, the tough, transparent cornea protects the eye. The cornea also helps focus light. Most of the change in the direction of the rays takes place at the cornea. And the cornea helps contain the aqueous humor, a liquid that nourishes the front part of the eye. Look at Figure 3-2.

★ 3-3. In addition to helping to focus light, what does the aqueous humor do?

The lens (Figure 3-2) also helps focus light on the retina. It is adjustable. A ring-shaped muscle surrounds the lens. It can make the lens change shape. This allows the eye to focus on near or far objects – a process called *accommodation*.

● 3-4. How is the lens of the model eye used in Activity 2 different from the lens in a human eye?

The vitreous humor helps focus light on the retina. It is a transparent jelly filling the interior of the eye. It's also an aid in holding the eye in its proper shape. It works like the trapped air in the balloon part of your model.

Important as the formation of an image is, the eye parts have other necessary jobs to do. For instance, the amount of light entering the eye needs to be controlled. You must have enough light to see clearly. But too much light can damage your eye. The iris helps to control the amount of light entering the eye through the pupil.

● 3-5. Tell what the iris in your eye looks like.

● 3-6. The iris in your eye can do something that the iris on the model eye in Activity 2 can't do. What is it?

A short investigation can show you how the iris works. You need a partner. Try to find someone who is doing this same activity, and you can run tests on each other. All you'll need is the scale of pupil sizes in Figure 3-3 (page 15).

SUBJECT	PUPIL SIZE (in mm)	
	Facing Toward Light	Facing Away from Light
Partner		
Yourself		

A. In your notebook, make a table similar to this one.

CAUTION

Never look directly at the sun.
The image of the sun on your retina
can cause permanent damage to
your sight.

B. Have your partner face a window or lighted area. Hold your book close to your partner's face and just below the eyes. Slide the book sideways until the black dot on the scale matches the pupil of one of your partner's eyes. Record the size in the table in your notebook.



C. Now have your partner face away from the window or lighted area. Measure the pupil size and record it.

If the subject has a very dark iris, the pupil size may be hard to measure. Just look close. You can do it.

D. Change places with your partner, and repeat Steps B and C. This time it's your iris size that should be measured and recorded twice.



9.0 mm



8.5 mm



8.0 mm



7.5 mm



7.0 mm



6.5 mm



6.0 mm



5.5 mm



5.0 mm



4.5 mm



4.0 mm



3.5 mm



3.0 mm



2.5 mm



2.0 mm



1.5 mm



1.0 mm



● 3-7. Did your partner's pupil change size during the tests?
If so, which way did it change?

Figure 3-3

● 3-8. Did your pupil change size during the tests? If so, which
way did it change?

Pupil size varies with conditions. For instance, your pupil size may change when you switch your gaze from a distant object to an object that is close up. You and your partner may want to try measuring this change. Pupil size is also affected by emotions.



E. While watching your partner's pupils, have him or her think of someone he or she really likes.

- 3-9. Describe the change, if any, in your partner's pupils.



The pupil looks black because it is just a hole in the iris. When you look into the pupil, it's like looking into a darkened movie theatre.

Changes in pupil size are made automatically by the iris. It is responding to signals from the retina, the light-sensitive layer at the back of the eye. This type of control is called *feedback*. A feedback loop is shown in Figure 3-4 below.

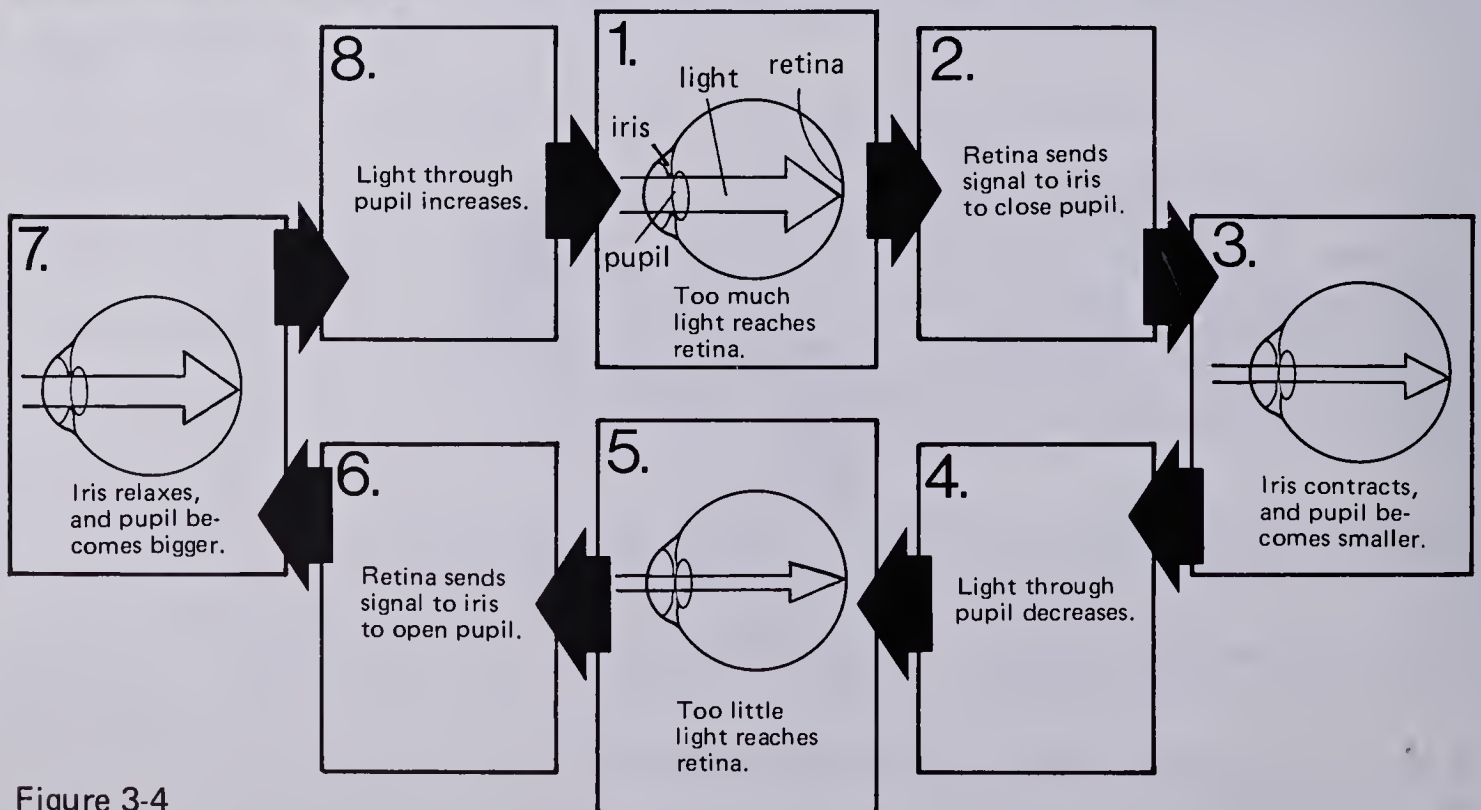


Figure 3-4

★ 3-10. Suppose you were reading this page and the lights dimmed. What do you think your iris would do?

You may have had trouble with the feedback diagram in Figure 3-4. Perhaps it's the first time you've seen this idea of feedback. If so, don't worry if it isn't completely clear. You'll see feedback diagrams in other minicourses. But if you've seen them before and still feel unsure, you may want to read "Resource Unit 13: Systems and Feedback." It gives a more detailed description of feedback.

There's another important thing that the eye must be able to do. It must be able to turn to track a moving object or scan a large object. This is made possible by muscles that turn the entire eyeball, as shown in Figure 3-5 below.

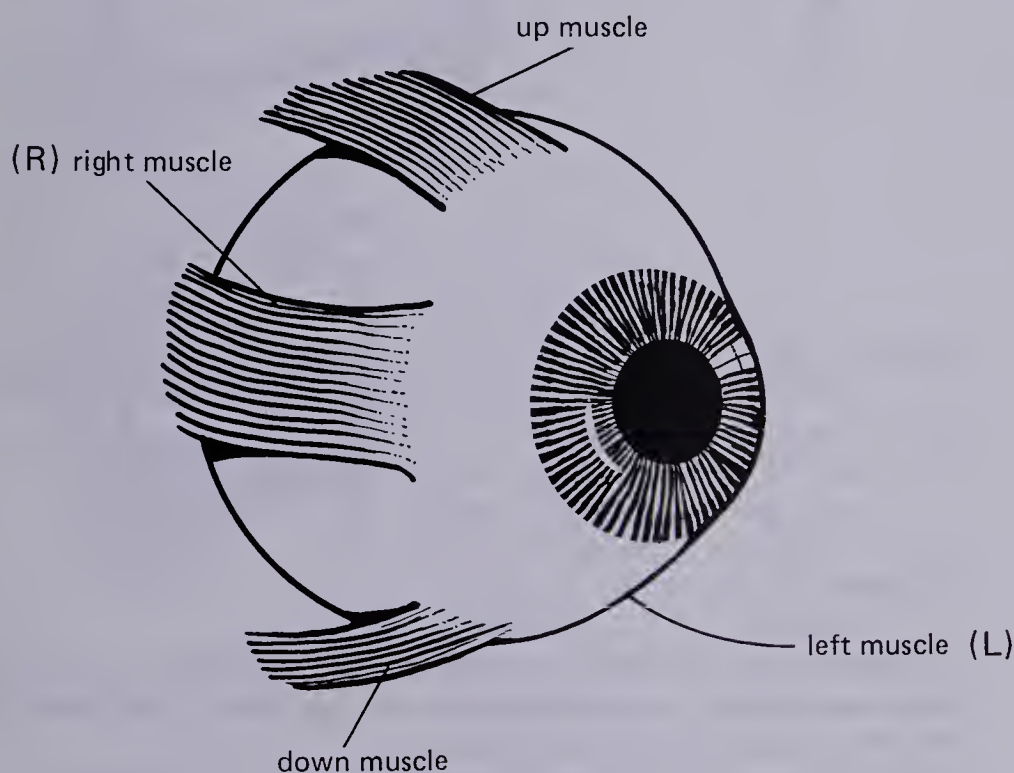


Figure 3-5

★ 3-11. Suppose Muscle L in Figure 3-5 above tightened up. Which way would the eyeball turn?

- 3-12. Which way could Muscle R turn the eyeball?
- 3-13. Images formed on the retina must be changed to nerve impulses to go to the brain. Otherwise a person "sees" nothing. What structure of the eye carries visual impulses to the brain?

ACTIVITY 4: IN FOCUS

You have probably seen snapshots that would have been good pictures except that they were all blurry. Maybe the subject was moving. Or maybe the camera was moving. Or maybe the camera lens was out of focus.

To get a sharp, clear image on film, a photographer has to focus the camera correctly. This is done by choosing the proper distance between the lens and the film. Look at Figure 4-1 below.

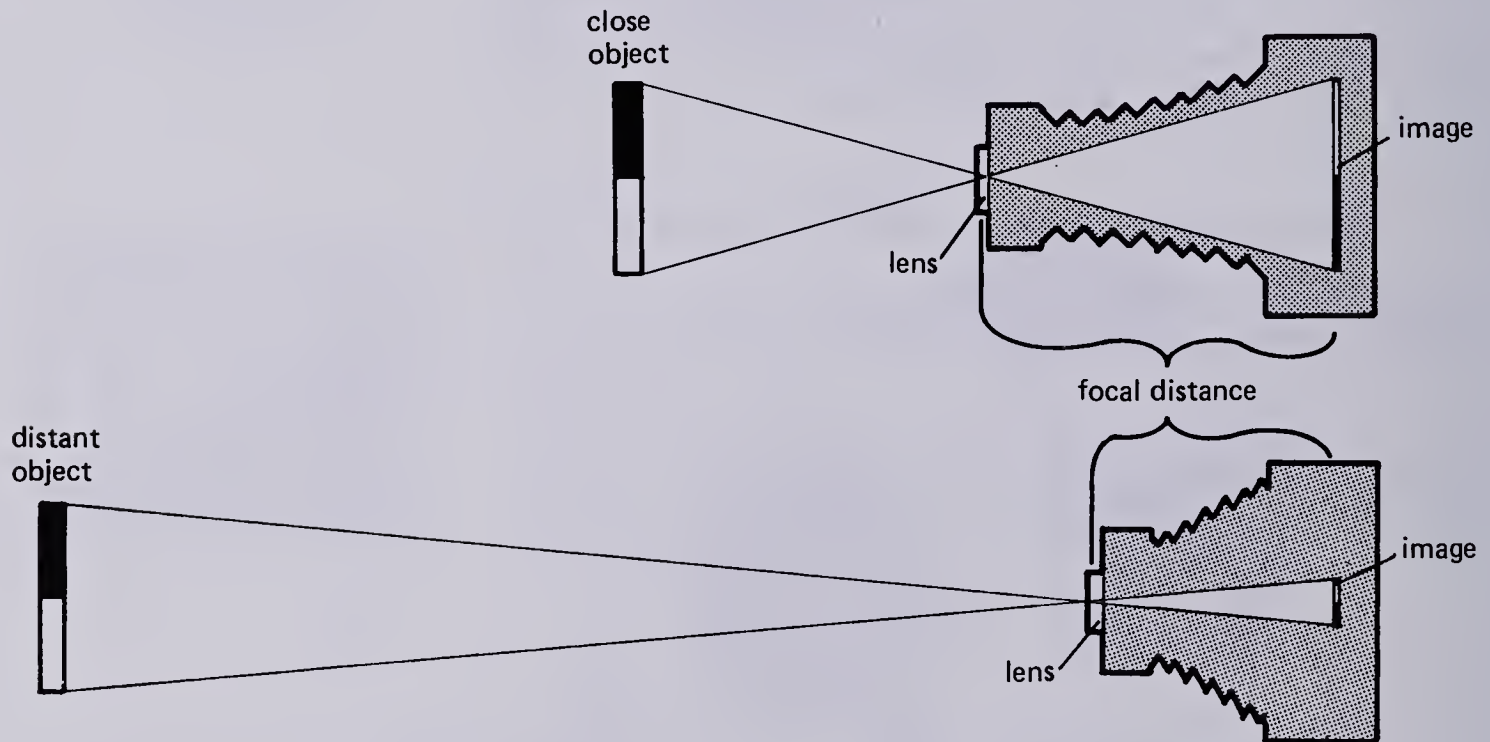


Figure 4-1

When an object that's far away is photographed, the distance from lens to film — the focal distance — is short. The image on the film should be small and sharp.

On the other hand, when the same object is photographed up close, the distance from lens to film has to be greater. The image on film should be large and sharp. The focal distance, then, depends on the distance between the object and the camera. The farther away the object, the shorter the focal distance. And the closer the object, the greater the focal distance.

Like a camera with a movable lens, your eye can focus on objects at various distances.

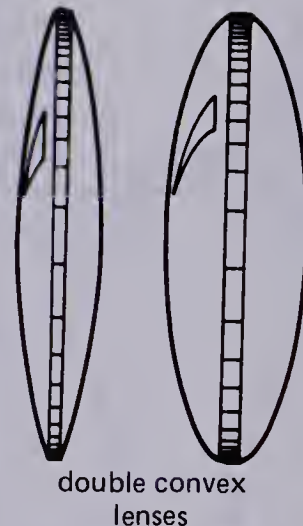
- 4-1. Do you think that focusing your eye is the same as focusing a camera — by moving the lens?

The human eye doesn't focus like a camera. The eye focuses on near or distant objects by changing the shape of the lens. When the eye muscle is relaxed, the lens becomes fairly thin. That's for distant vision. The muscle makes the lens thicken in order for the eye to focus on nearby objects. This process is called *accommodation*.

● 4-2. How does the human eye change the shape of its lens?

The eye muscle is around the edge of the lens in your eye. This muscle can change the shape of the lens. But how does that affect focus? To answer that question, you need to know about lenses. Let's take a look at two differently shaped lenses. You'll need the following.

- 2 double convex lenses, one thicker than the other
- 30 cm² white cardboard
- light socket with cord
- 100-W or 150-W light bulb
- metre stick
- egg-carton lens holder
- felt-tip pen with red ink
- felt-tip pen with black ink

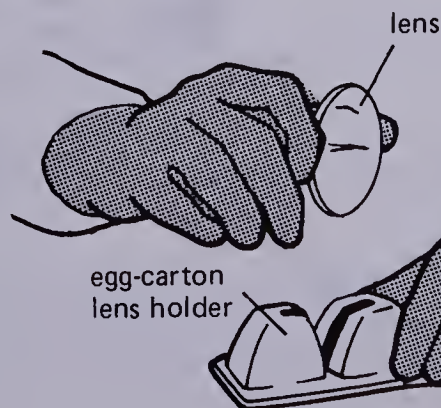


A candle may be substituted for the bulb, socket, and two felt-tip pens. The candle flame is used as the light source.

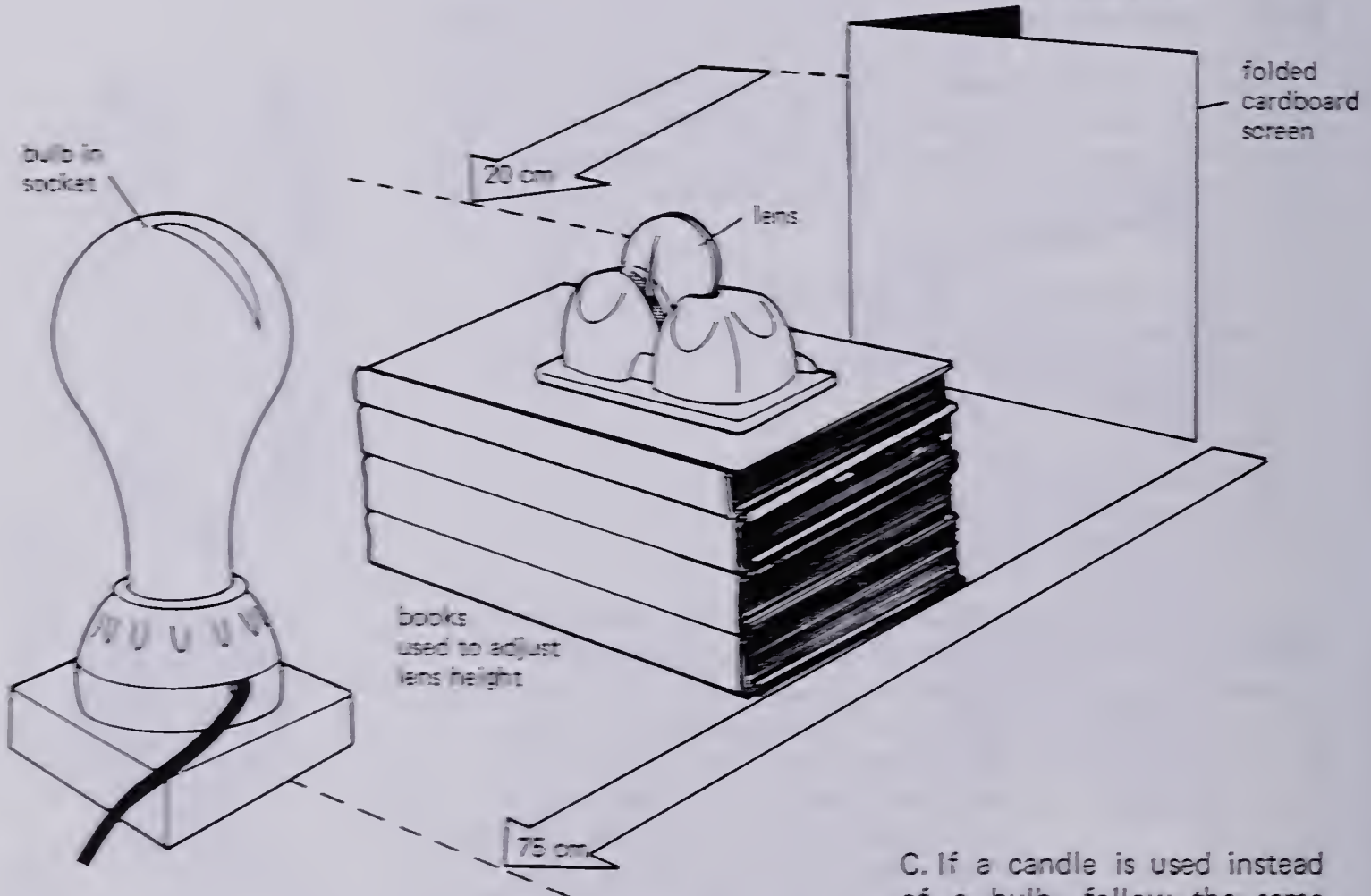
CAUTION

Handle the lenses carefully. They can be easily scratched. Treat them like your favorite phonograph record. Hold them by the edges, and keep fingerprints off the surfaces. Clean them with soft tissues only.

A. Wedge the thinner and less curved lens into the valley of the egg-carton holder. The holder will work fine if the lens is not jammed into it too deeply.

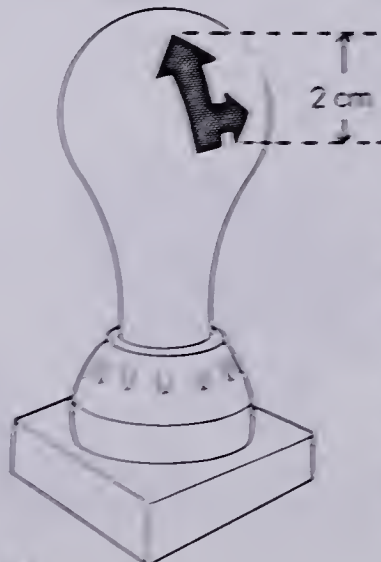


B. Set up the light, lens, and screen as shown. You'll need a flat surface about one metre long. The bulb should be about 75 cm from the screen. The lens should be exactly 20 cm from the screen.

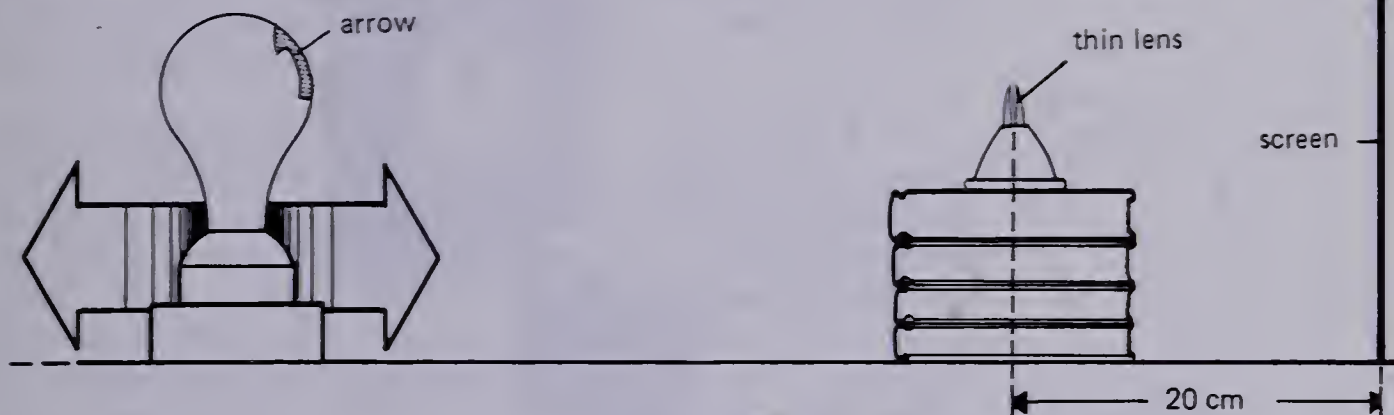


C. If a candle is used instead of a bulb, follow the same directions but skip this step. Wherever it says *bulb*, think *candle*.

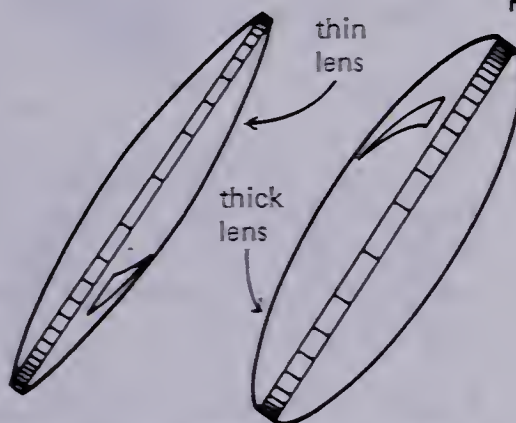
Decide which side of the bulb will face the lens and screen. On that side of the bulb, use a red felt-tip pen to draw a 2-cm long, fat, two-headed, red arrow. The two arrowheads should be at right angles. Use the black felt-tip pen to give the arrow a black border.



D. Light the bulb. Move it back and forth until you get the sharpest possible image of the arrow on the screen.



E. Replace the thin convex lens with the thicker and more curved convex lens. Don't move the holder. Keep the lens exactly 20 cm from the screen. Focus the image by moving the light bulb toward the screen or away from it.



- 4-3. Which lens produced a larger image — the thinner lens or the thicker lens?
- 4-4. With which lens did the bulb have to be closer to the screen — the thinner lens or the thicker lens?

Inside your eye, there is a certain distance between the lens in the front and the retina in the back. Let's call this distance the *length of the eye*.

- 4-5. In your investigation, what distance represents the length of the eye?
- 4-6. In focusing the image in the eye, does the length of the eye change?

If you're not sure of your answer to Question 4-6, review Activity 2. Remember that in your investigation, you kept the distance between the lens and the screen the same for the two lenses.

Figure 4-2 below shows a sketch of an eye overlaid on the equipment you have been using. It should suggest to you that your eye works in a similar way.

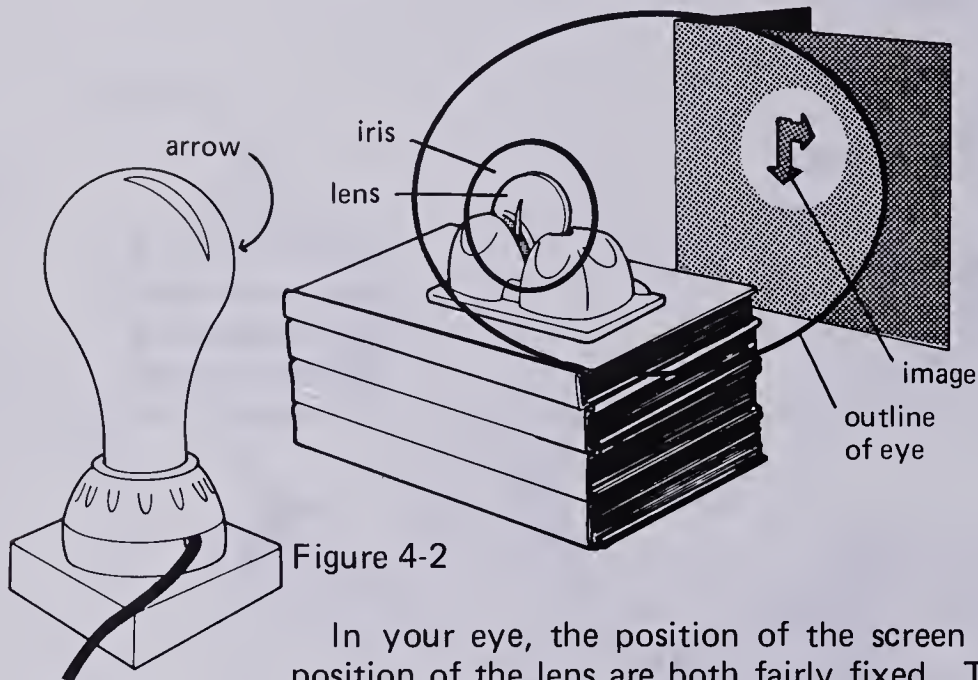


Figure 4-2

In your eye, the position of the screen — retina — and the position of the lens are both fairly fixed. The distance between them changes very little. Therefore, in your investigation, it was necessary for the distance between the lens and the screen to stay the same.

- 4-7. Even when the lens-to-image (screen) distance is fixed, you can focus the images of both distant and close objects. What do you change?

Your eye doesn't change lenses, of course. But it does change the shape of the lens that is there. It makes the lens thicker and more curved or thinner and less curved. Look at Figure 4-3 at the left.

- ★ 4-8. When an object is brought closer to the eye, does the lens get thicker and more curved or thinner and less curved?

- 4-9. Consider the way the lens in the eye adjusts. Which do you think the lens is — hard and inflexible like a camera lens or flexible and elastic?

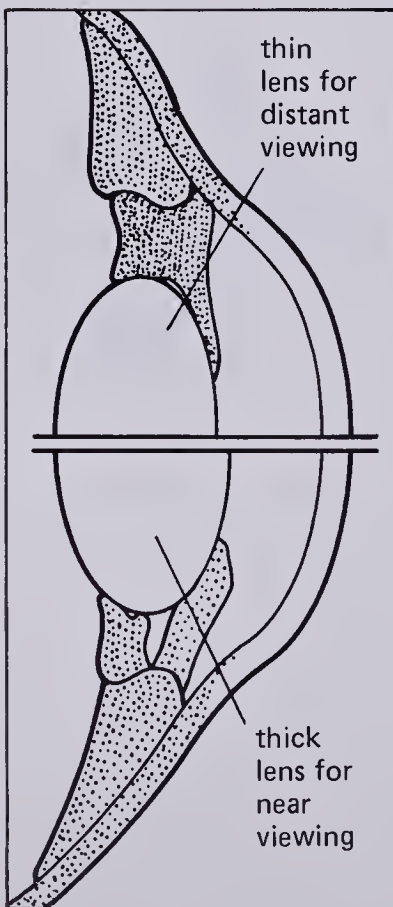


Figure 4-3

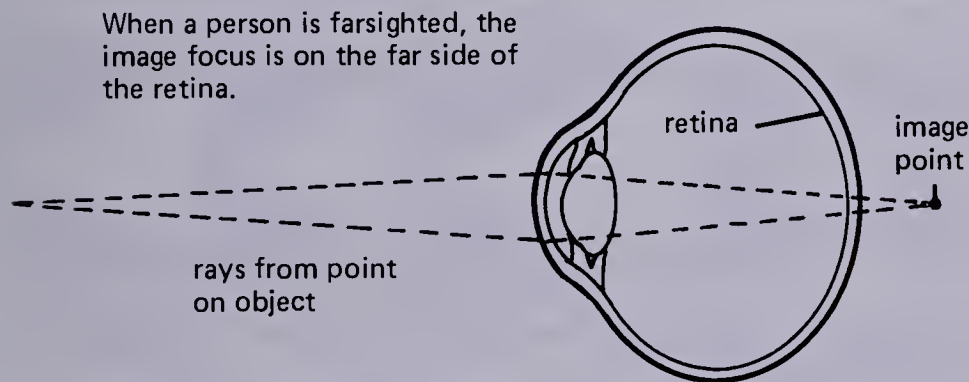
Generally, human eye lenses are fairly flexible. They get thicker or thinner as needed. But some people's eye lenses just won't adjust properly. Lenses tend to become inflexible with age. They gradually get set in a thin shape. This causes a problem called the *sight of old age*.

- 4-10. As the lens of the eye becomes less flexible, how is vision affected? Could this happen to you?

The sight of old age probably doesn't affect you now. It's part of the aging process. And it happens gradually. But some people your age do have trouble seeing clearly. There are a number of different reasons. Here are three of them.

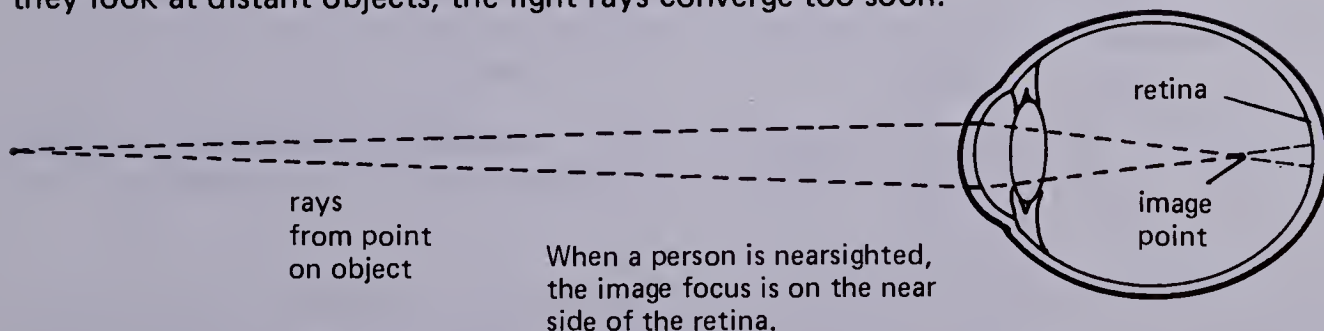
FARSIGHTEDNESS

Some people are born with or develop lenses that can't bring the light from nearby objects to a focus inside the eye. The best they can do is focus the light at a point that would be behind the retina. You can think of such persons as having eyeballs too short for their lenses. They are called *farsighted* because they can see better at a distance than they can up close. When they look at nearby objects, the light rays don't converge soon enough.



NEARSIGHTEDNESS

Other people have the opposite problem. Their lenses tend to focus light from distant objects at a point inside the eyeball but short of the retina. Such people are called *nearsighted*. They see well up close but have trouble seeing objects at a distance. When they look at distant objects, the light rays converge too soon.



☆ 4-11. What is the ability to focus only on objects near the eye called? In this case, do distant objects focus on the near side or the far side of the retina?

☆ 4-12. What is the ability to focus only on objects at a distance called? In this case, do nearby objects focus on the near side or the far side of the retina?

More young people wear corrective lenses for nearsightedness than for farsightedness.

Perhaps you'd like to try to "prescribe" some glasses yourself. Of course, you can't really make eyeglasses, but you can get a good idea of how they work.

First you have to know how lenses change the path of light. A convex lens is a lens that is thicker in the center than at the edges. It tends to converge the light — bring it together. A concave lens is a lens that is thinner in the center than at the edges. It tends to diverge the light — spread it apart. Look at Figure 4-4 below.

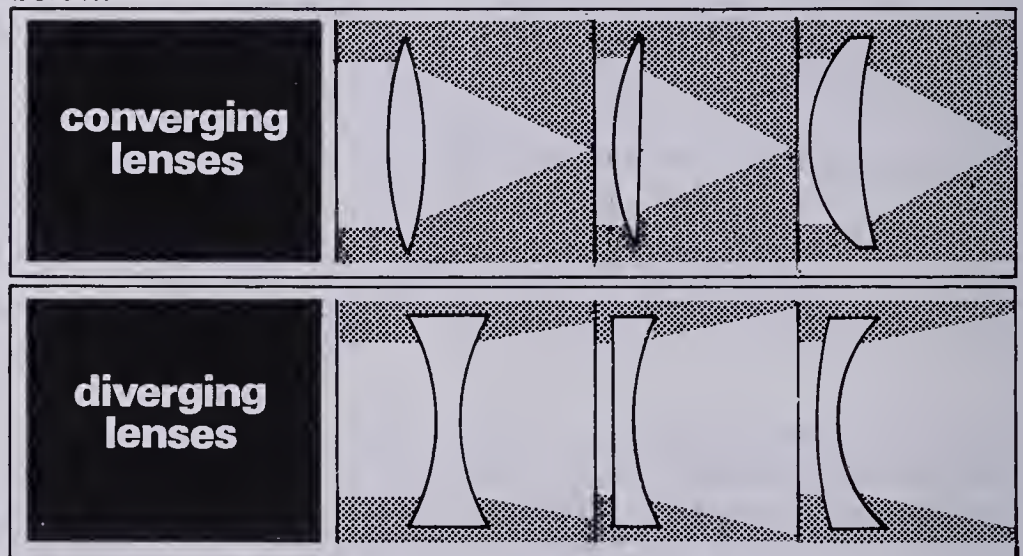


Figure 4-4

If objects tend to focus on the near side of the retina, the light must be diverged. If objects tend to focus on the far side of the retina, the light must be converged.

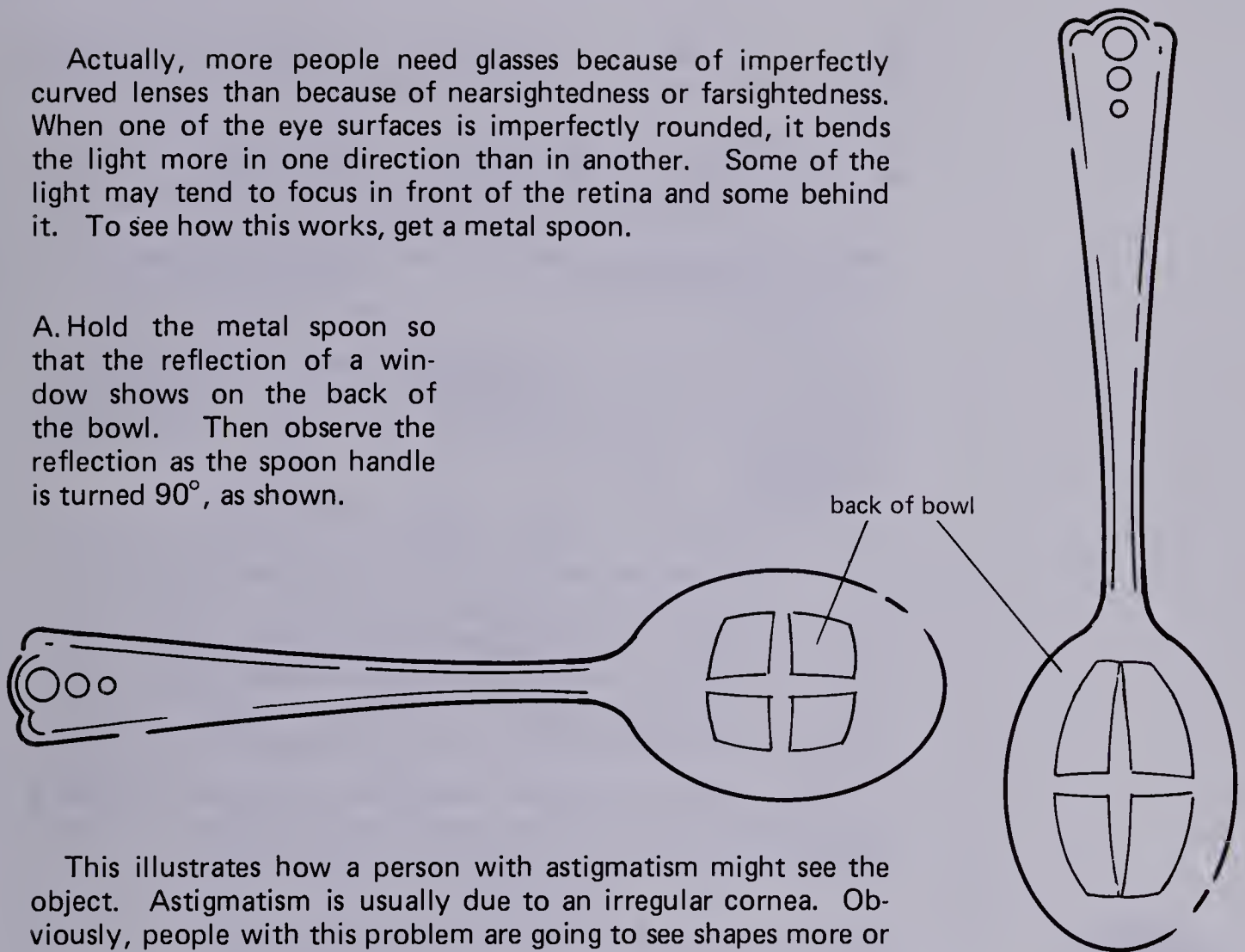
☆ 4-13. Which type of lens — converging or diverging — should be used to correct for nearsightedness? For farsightedness?

ASTIGMATISM

So far, it's been assumed that the outer surface of the cornea and both sides of the lens in the human eye are always nicely rounded like parts of spheres. This is seldom true.

Actually, more people need glasses because of imperfectly curved lenses than because of nearsightedness or farsightedness. When one of the eye surfaces is imperfectly rounded, it bends the light more in one direction than in another. Some of the light may tend to focus in front of the retina and some behind it. To see how this works, get a metal spoon.

A. Hold the metal spoon so that the reflection of a window shows on the back of the bowl. Then observe the reflection as the spoon handle is turned 90°, as shown.

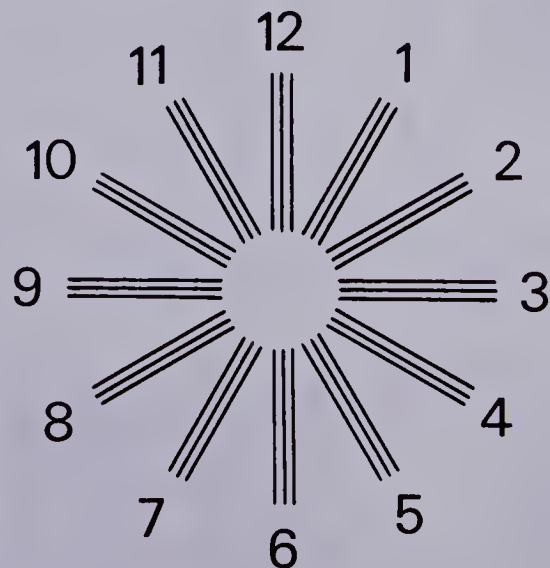


This illustrates how a person with astigmatism might see the object. Astigmatism is usually due to an irregular cornea. Obviously, people with this problem are going to see shapes more or less distorted.

Try the following simple test to see whether you are astigmatic.

B. Look carefully at the radiating lines. Sets of lines in some directions may appear darker or clearer than those in others. If so, you may be astigmatic.

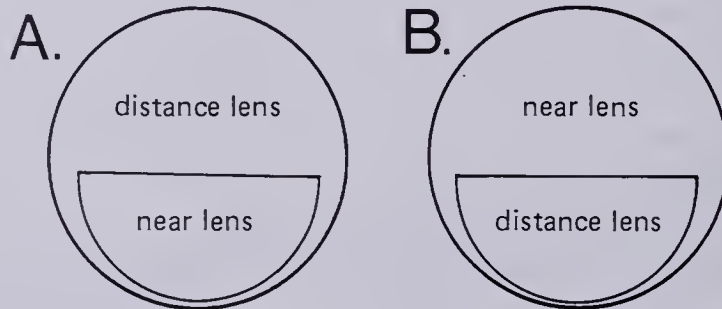
C. Ask several of your classmates to look at the same diagram and tell you what they see.



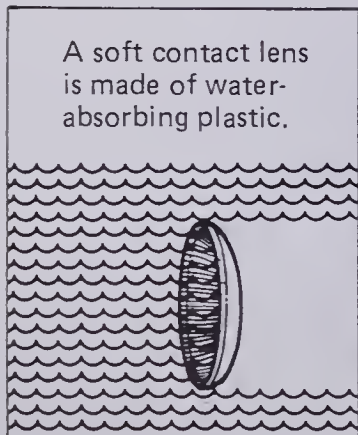
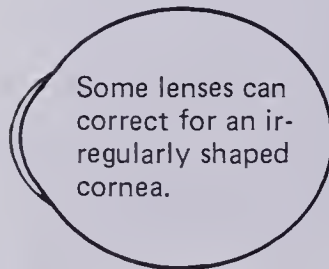
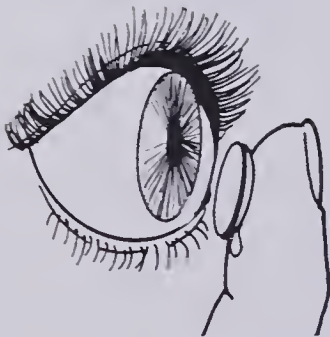
- ☆ 4-14. When one of the eye surfaces is imperfectly curved, what vision defect may occur? What effect would this have on vision?

Some people have more than one vision problem. They may not be able to see either near or distant objects easily. Such people are often fitted for bifocal (two-part) lenses. One part of each lens corrects for near vision and the other part for distant vision.

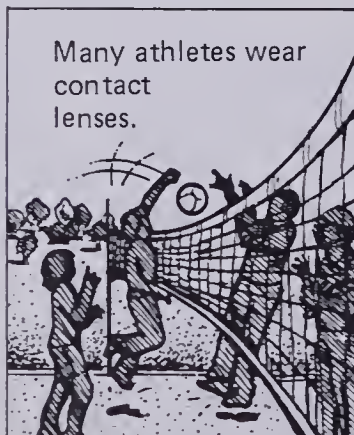
- 4-15. Look at the combination of corrective lenses below. Which lens — A or B — might be recommended for an elderly typist who has trouble both reading and seeing at a distance? Explain your choice.



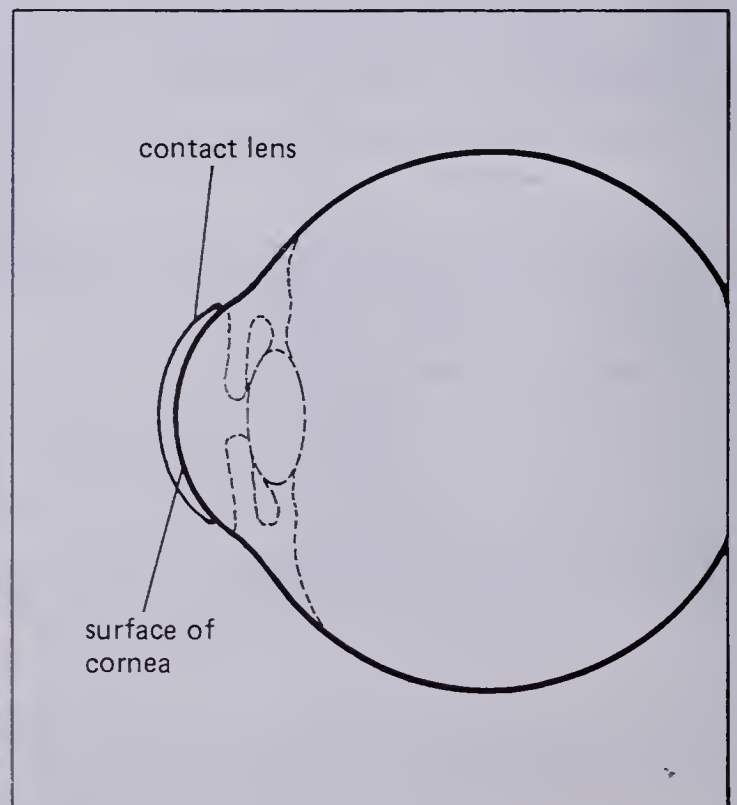
Contact lenses are widely used today. Because they aren't very noticeable, you may not realize that many people are wearing them.



A soft contact lens is made of water-absorbing plastic.



Many athletes wear contact lenses.



ACTIVITY 5: GETTING GLASSES

Suppose you are having some trouble with your vision. The printing in textbooks looks blurred to you, and you can't see too well at a distance either. Consider what you should do.



Should you go to a medical doctor? Or should you have your eyes examined? Or should you just rest your eyes, or what?

If you don't wear eyeglasses or have never had a complete eye examination, you may not know the answer. Several professions deal with the eyes, and there is some overlap in the services they provide. Before going to any eye professional, a person ought to know what each kind can and cannot do. Look at Figure 5-1 below.

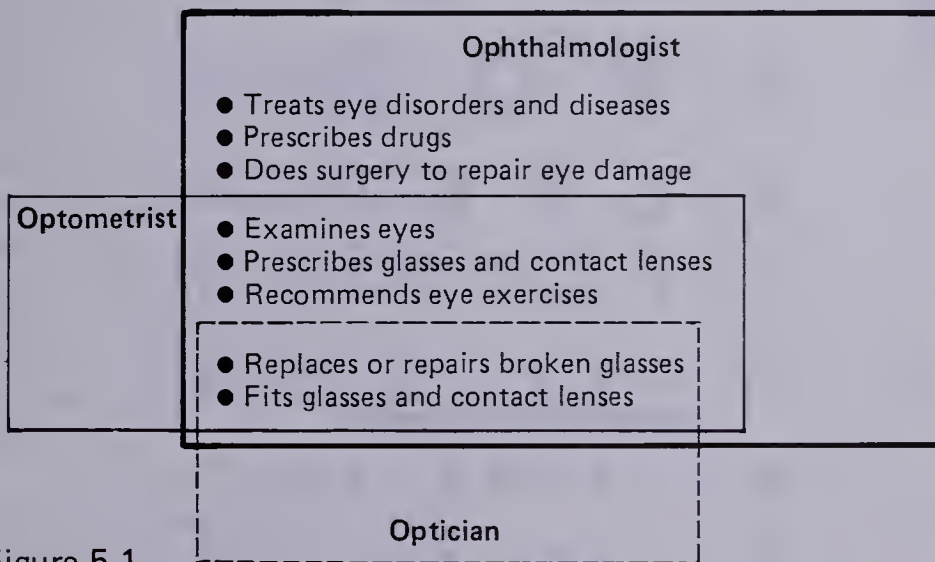


Figure 5-1

- 5-1. Suppose you were having the eye troubles described in each case below. Which of the three professionals listed in Figure 5-1 above would you see first for each?
 - A. The lens of one of your glasses is scratched.
 - B. You have an eye infection.
 - C. You've flunked the vision part of your driver's test and need glasses for the first time.

Notice in Figure 5-1 (page 27) that an ophthalmologist could handle any of those things. Whereas an optician is restricted to fitting and repairing corrective lenses, an optometrist can also write prescriptions for them.

Before prescribing corrective lenses, the optometrist or ophthalmologist will do a four-part examination.

What comes first during the examination will vary with the doctor. But somewhere along the way, the patient will be given an eye test. The Snellen test, using a chart like the one shown in Figure 5-2 below, is often given. It was developed at the turn of the century by a Dutch eye doctor, Herman Snellen. A Snellen chart is in almost every school in the United States now.

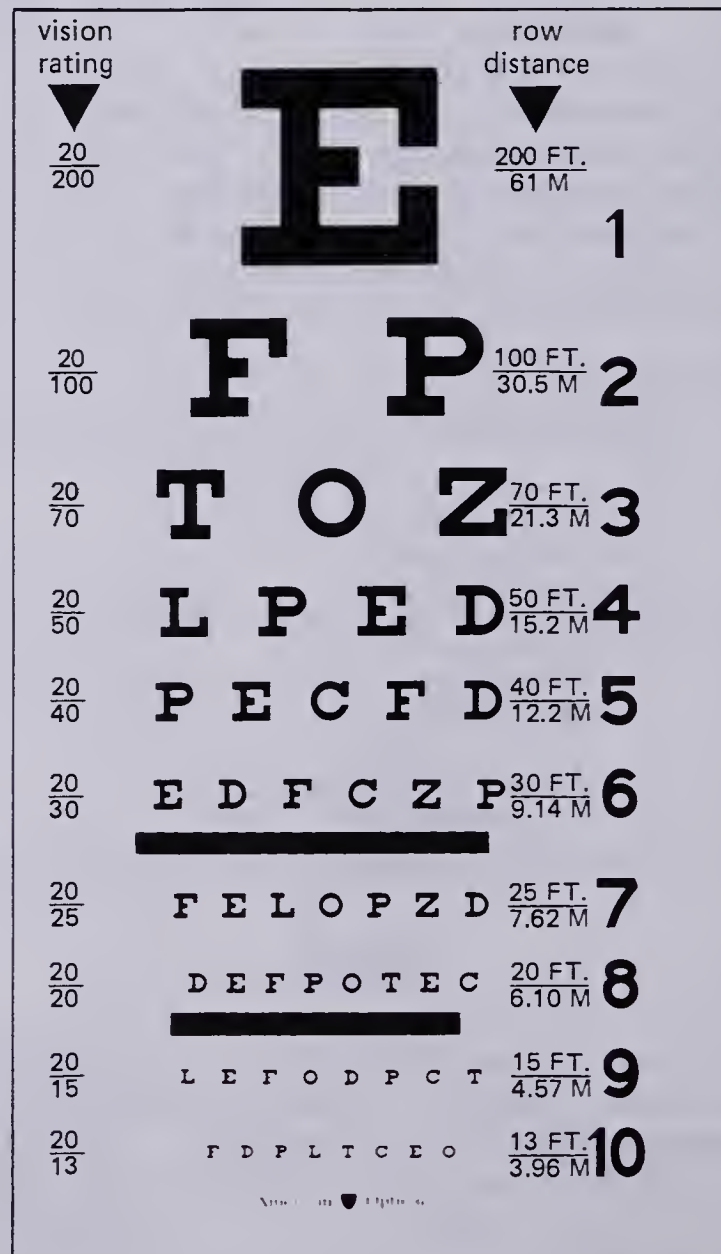


Figure 5-2

Try taking the Snellen test. You'll need a partner and the following materials.

Snellen chart
metre stick or yardstick
masking tape

A. In your notebook, make a table similar to this. You'll use the first blank column to fill in the row numbers as you take the test. The remaining columns you can fill in later.

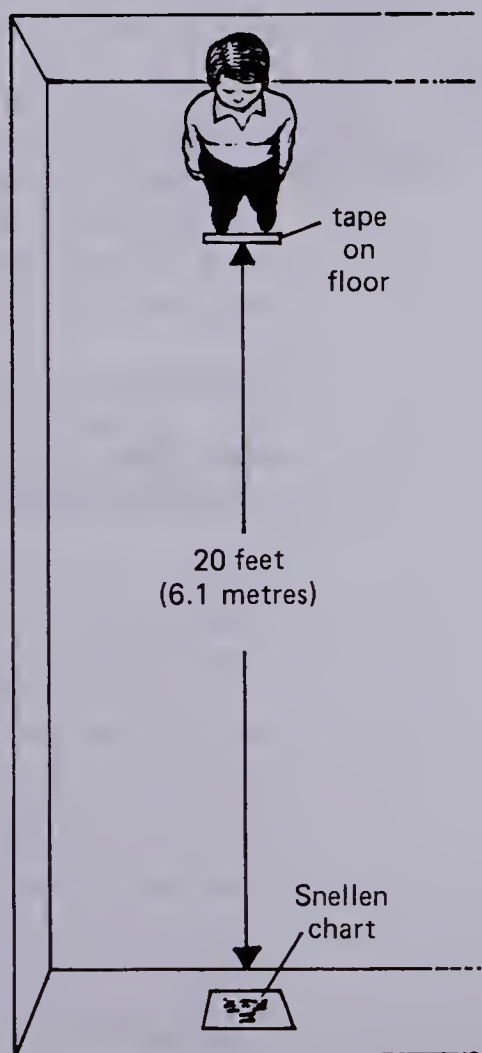
GLASSES	EYE(S)	DISTANCE FROM CHART (in feet)	SMALLEST READABLE ROW		VISION RATING
			Row Number	Row Distance (in feet)	
Without glasses	both	20			
	left	20			
	right	20			
With glasses (if you wear them)	both	20			
	left	20			
	right	20			

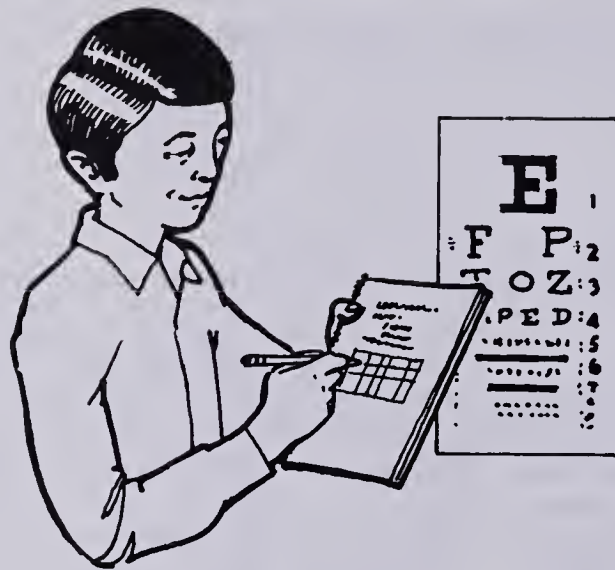
B. Mount the Snellen chart on a well-lit wall. It should be a place that you can easily view from a spot that is 20 feet (6.1 metres) directly in front of the chart. Mark the spot on the floor with a strip of masking tape.

C. Stand just behind the tape mark. Have your partner point to different letters on the chart. Ask your partner to find the row having the smallest letters you can read with both eyes open. *Read* means being able to name at least half of the letters correctly. Enter the number of that row in the appropriate column on your table.

D. Repeat the test with the left eye alone. Then repeat it with the right eye alone. Record in your notebook, the number of the smallest row you can read.

E. Repeat the test with glasses if you have them. Otherwise, skip that part of the table.





F. Complete the table by filling in the remaining columns with the information required. You can do this very easily by referring back to Figure 5-2 (page 28). Both the row distance and the vision rating for each row number are shown there before the row number.

You'll notice that the table calls for the distances in feet, not metres. The reason for that is that vision ratings are still given only in terms of feet. This test could be done using only the metric system. But you're probably more accustomed to hearing the results given in the English system.

The vision rating is a way of comparing the vision of your eyes with the vision of a normal eye. For instance, suppose the smallest letters you could read from 20 feet were in Row 6. That's a row distance of 30 feet. This means that from 30 feet a person with normal vision can read those same letters. So you could see at 20 feet what a perfect eye can see at 30 feet. In such a case, your vision rating would be 20/30.

- 5-2. What rating would show that your eyes were normal?
- 5-3. According to the Snellen test, is your vision rating normal, worse than normal, or better than normal?
- 5-4. Is this version of the Snellen eye chart used to test for distant vision or near vision?

The Snellen chart you used is designed to reveal problems with seeing distant objects. There's a different test to tell how well you see close up, as in reading.

Vision tests can tell whether or not you need glasses. But the tests are only part of a full examination. And more information is needed before the doctor can write an accurate prescription for your lenses. The second part of the examination might be the taking of your case history. The doctor might ask a lot of questions and take notes on everything about you that could possibly affect your eyes.

Your eye doctor might ask for information such as the following.

- Do you have any specific complaints?
- Is anything bothering you?
- Do your eyes ache, burn, or tire easily?
- Does print blur?
- Do you have headaches? When do they occur and in what part of your head?
- Are you troubled by nausea, dizziness, indigestion, or nervousness?
- Do you have a job?
- Where are you employed?
- Do you do much welding, typing, art, writing, reading, or inspecting?
- Are you a golfer, boater, tennis player, hunter, or motorcyclist?
- Do you go to the movies often, play cards often, watch television for hours at a time?
- Are you taking any treatment for a physical condition of any kind?
- Are you right-handed or left-handed?



Note that the eye doctor might ask about headaches and nausea. These can indicate vision problems.

The eye doctor needs to know about anything that might be affecting your vision. The doctor also wants to know how you use your eyes. That can be important to your prescription for glasses. It may indicate the sorts of lenses and frames that would suit you best.

- 5-5. In an eye examination, why will the doctor ask you about your work, your hobbies, your social activities, and your forms of recreation?

In a third part of the eye examination, the doctor checks the physical condition of your eyes, both inside and out.

- 5-6. Look into the pupil of a classmate's eye. Try to see the retina. Can you see it?

You probably can't see into the eye very far. Instead, you can probably see your own image reflected.

To look into the eye, optometrists and ophthalmologists use the ophthalmoscope. Figure 5-3 below shows an ophthalmoscope.

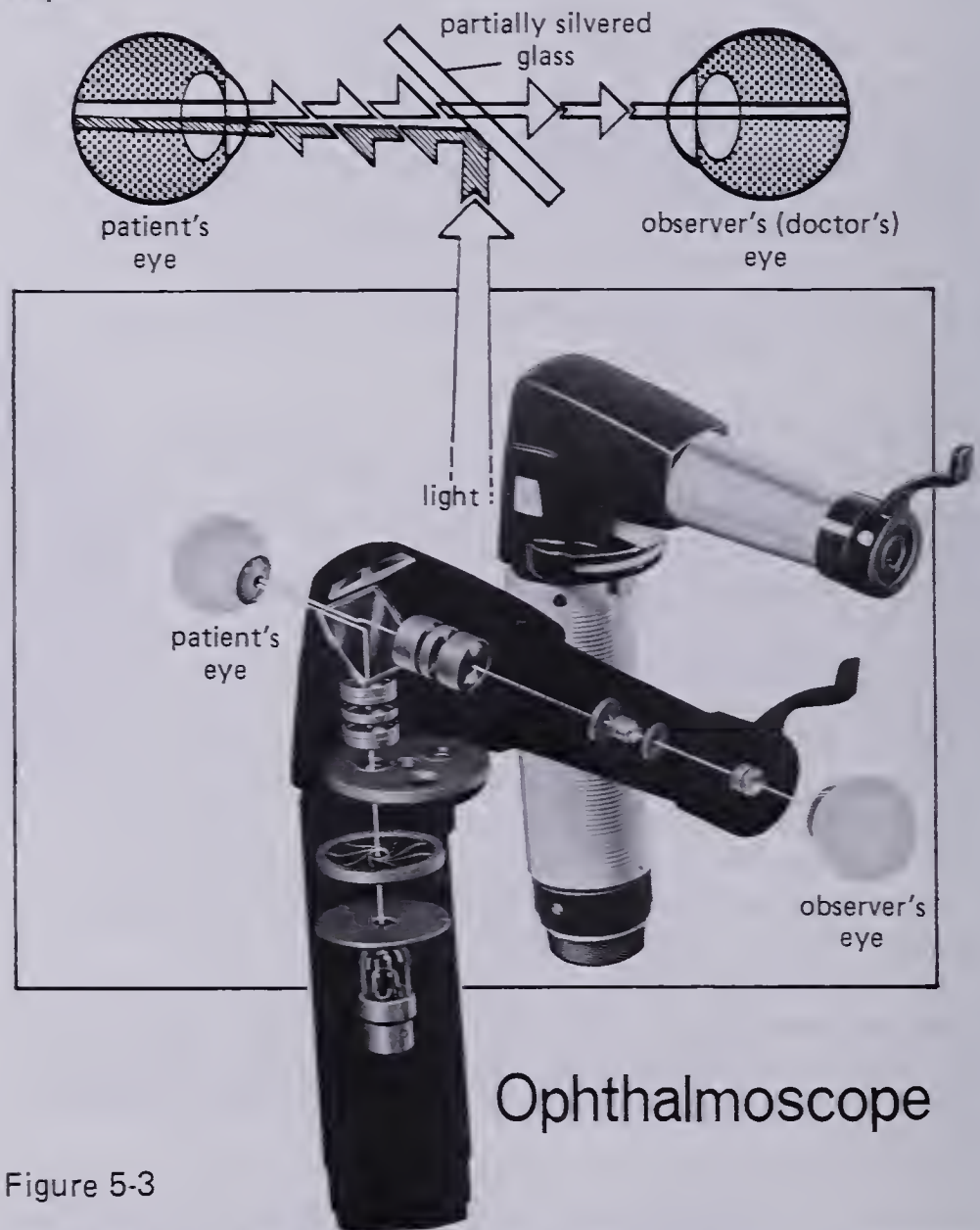


Figure 5-3

- 5-7. What part of your eye is the doctor examining with an ophthalmoscope?

In the fourth and final portion of the eye exam, the doctor figures out the prescription for your glasses — if you need glasses. This requires very accurate information about your eyes.

You'll be asked to look through lots of different lenses. You'll keep telling the doctor how well or badly you can see with the lenses. Many eye doctors conduct this part of the examination with a complicated instrument like the one shown in Figure 5-4 (page 33).

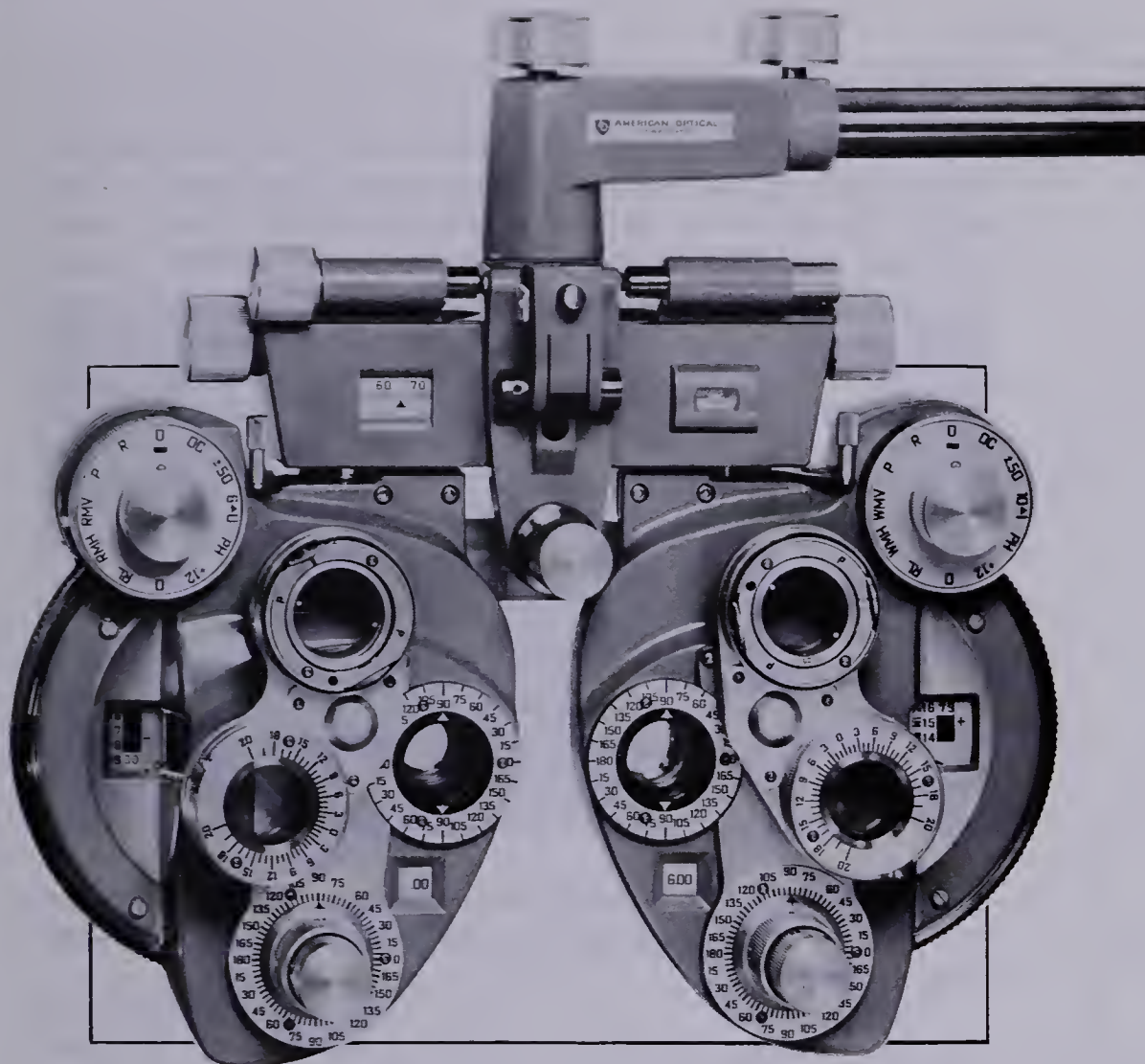


Figure 5-4

The doctor will ask you to look through the instrument to read an eye chart. By turning the dials, the doctor can make different lenses click in place in front of each of your eyes. You answer the doctor's questions about which lenses are the clearest for you.

The doctor will write out a prescription, using the findings. You take it to an optician, optometrist, or ophthalmologist for filling. Since each of your eyes is unique, you may have different lens prescriptions for the right eye and the left eye.

★ 5-8. Match each part of the eye exam with the kind of information collected by it.

Exam Part

- A. Vision Test
- B. Case history
- C. Physical exam
- D. Determining prescription

Information Collected

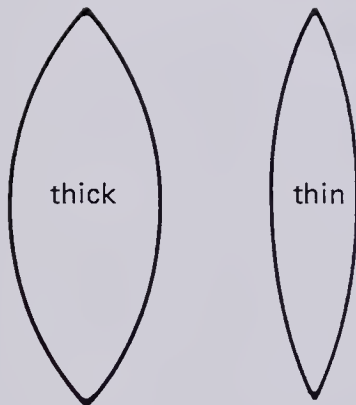
- 1. how you use your eyes
- 2. the exact lenses you need
- 3. how well you see
- 4. how healthy your eyes are now

ACTIVITY 6: USING LENSES

Lenses had been in use for hundreds of years before telescopes, microscopes, and projectors were invented. It took people like Galileo to discover how to put lenses together to get more use from them — uses such as seeing distant objects better.



convex lenses



To see how pioneers like Galileo invented optical instruments, you need to know more about lenses. Get the following equipment.

2 egg-carton lens holders

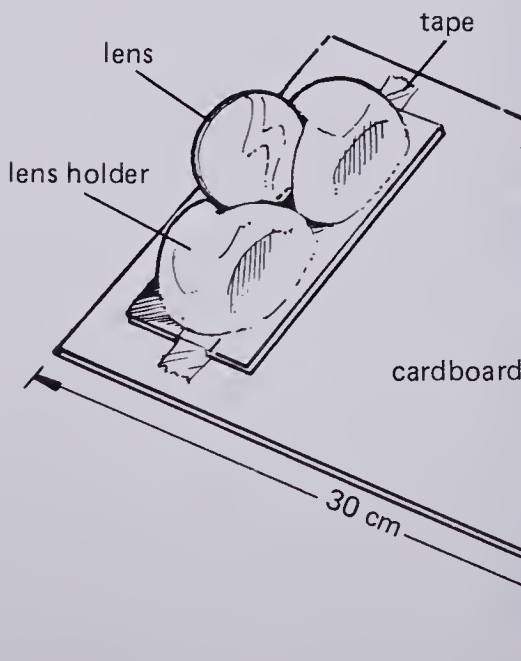
2 converging lenses (convex — thicker at the center than at the edges), one more curved and thicker than the other

white cardboard screen

piece of stiff cardboard, 30 cm long

tape

metric ruler

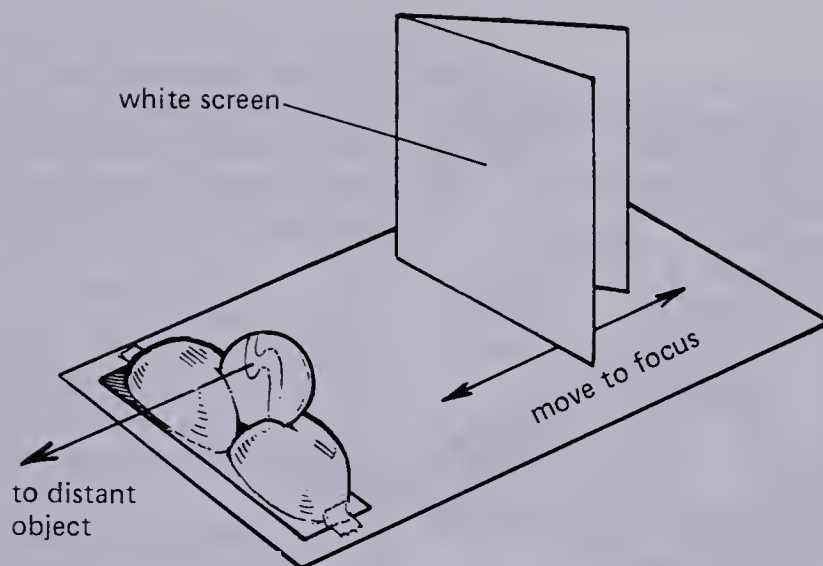


CAUTION

Don't look at the sun with any optical device. The sun can damage your eyes.

A. Place the thicker lens into the lens holder. Then use two small pieces of tape to fasten the lens holder to one end of the piece of cardboard, as shown.

B. Take the lens, white screen, and ruler to a spot where you can see a well-lit, distant object. The object should be 5 m or more away from the lens. Move the screen back and forth on the cardboard until the object is in sharp focus on the screen. Measure the distance from the lens to the screen.

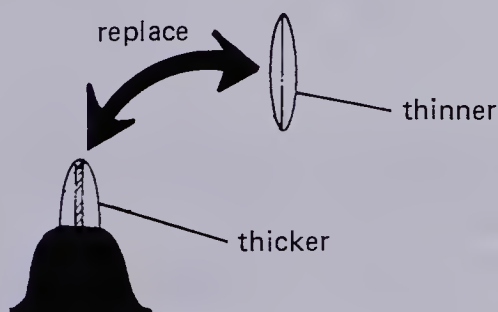


- 6-1. What is the lens-to-screen distance in cm for sharp focus?

The distance you measured is called the *focal length* of the lens. Objects at a great enough distance from the lens will form a sharp image at such a point. That point is called the *principal focus* of the lens.

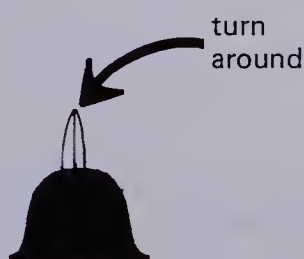
- 6-2. Is the image larger or smaller than the object? Is it upside down or right side up?

C. Replace the thicker lens with the thinner one. Find the principal focus and the focal length as you did before.

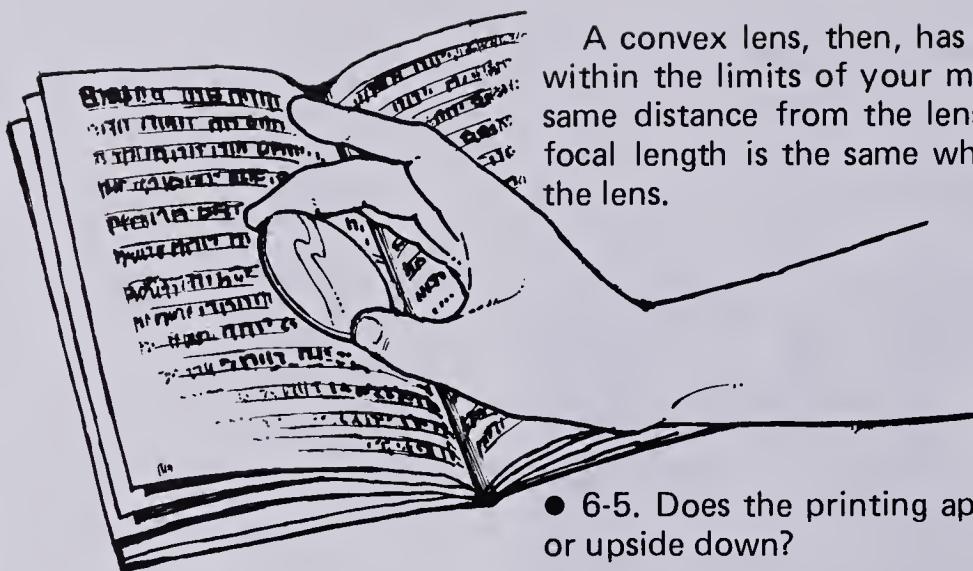


- 6-3. What is the focal length of the thinner lens?

D. Turn the lens around so that the opposite side faces the object. Again find the principal focus and the focal length.



- 6-4. Was the focal length about the same as before?



A convex lens, then, has a principal focus on each side. And within the limits of your measurement, the principal focus is the same distance from the lens on each side. That means that the focal length is the same whichever way the light passes through the lens.

E. Pick up either of the lenses by its edge. Hold it at a distance of less than the focal length from the printing in a book.

- 6-5. Does the printing appear larger or smaller? Right side up or upside down?

Let's sum up what you have found out about lenses. Look at Figure 6-1 below.

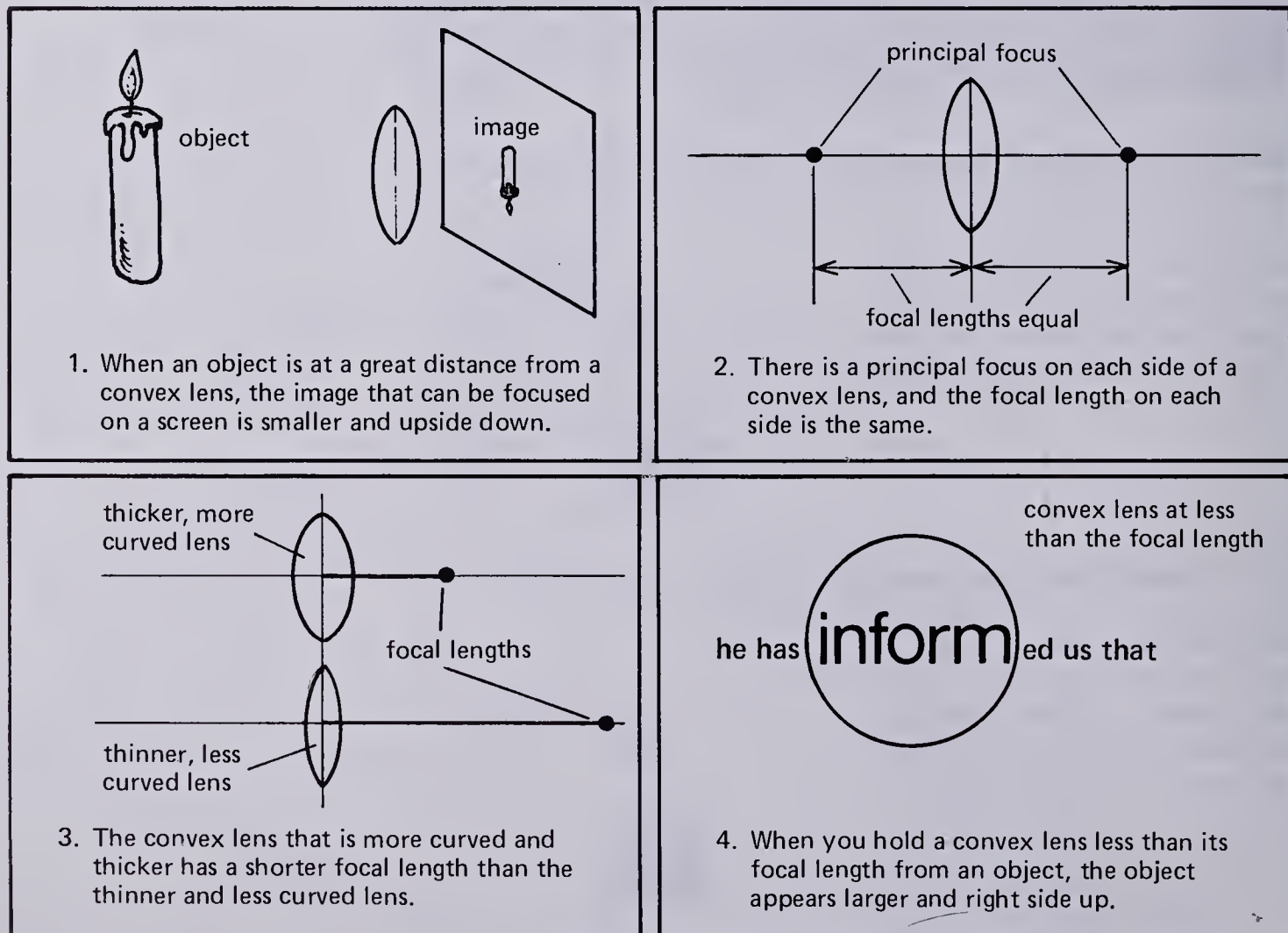


Figure 6-1

Point 4 illustrates an optical device. It's called a *simple microscope*, or *magnifier*.

☆ 6-6. When you use a convex lens as a simple microscope, or magnifier, where do you hold the lens in relation to the object you're looking at?

Optical devices can use more than just one lens. One such device is the telescope, used for looking at distant objects. With what you found out about lenses, you should have all the information you need to bring distant objects closer.

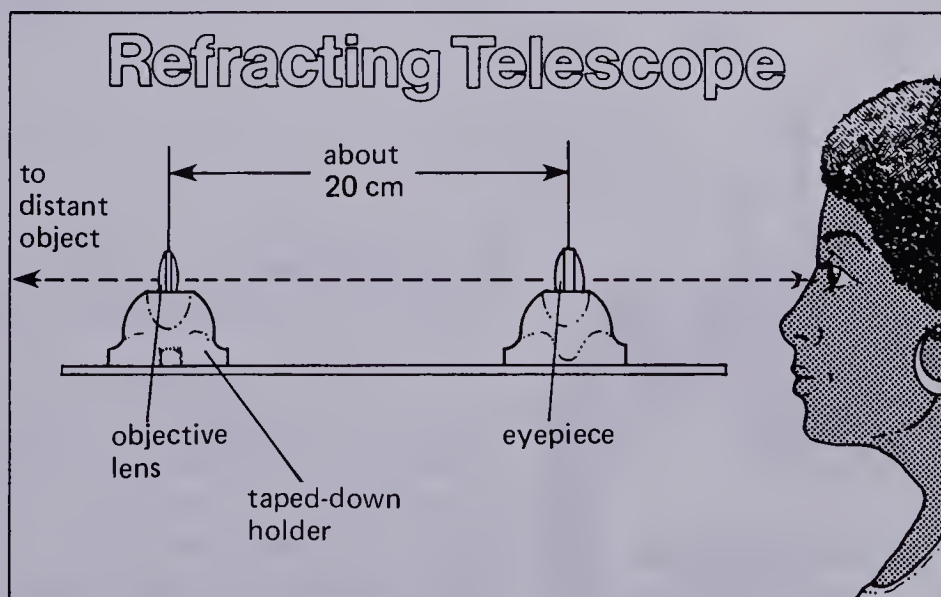
● 6-7. You focus an image of a distant object on a screen. Is the image larger or smaller than the object? Upside down or right side up?

● 6-8. Suppose you look at that small, upside-down image with the thicker lens at less than its focal length from the image. What will you see?

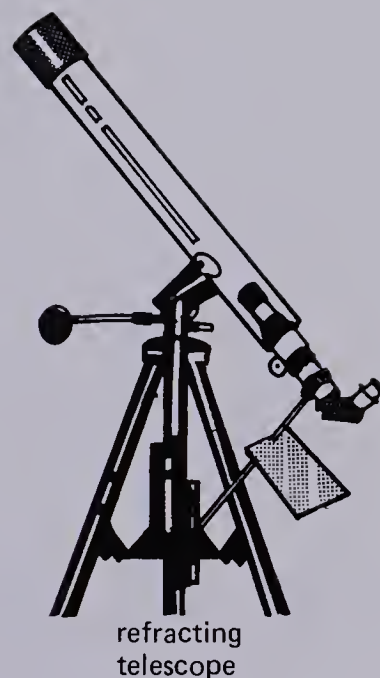
● 6-9. Suppose the focal length of the first lens (Question 6-7 above) is 15 cm. The focal length of the second lens (Question 6-8 above) is 5 cm. How far apart should the two lenses be to see the image of a distant object?

Let's try it.

F. One lens holder should be fastened to the end of the stiff cardboard with tape. Put the thinner convex lens into it. Put the thicker lens into the other lens holder. Position it about 20 cm from the thinner lens. Look at a distant object. Move the thicker lens back and forth to get a sharp image.



Two convex lenses arranged this way makes a refracting telescope. The lens closer to the object is called the *objective*. The lens closer to the eye is called the *eyepiece*.

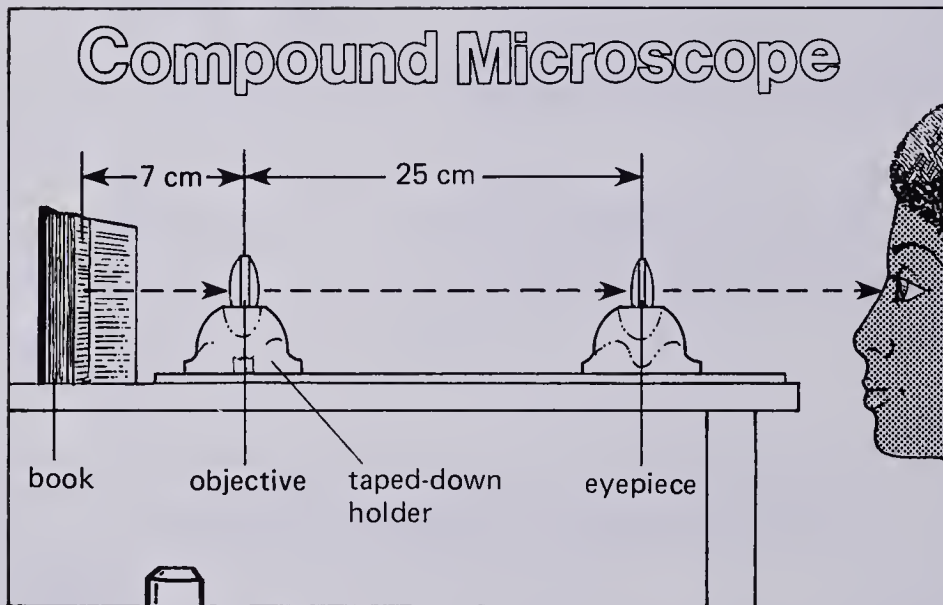


- ★ 6-10. Is the image formed by a refracting telescope larger or smaller than would be seen by the unaided eye? Is it upside down or right side up?

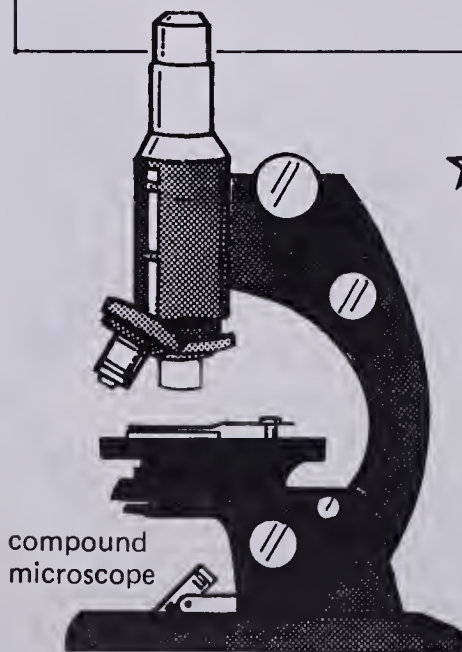
The number of times larger the image is than that seen by the unaided eye is called the *magnification*, or *power*, of the telescope. It can be found by dividing the focal length of the objective by the focal length of the eyepiece.

- 6-11. What is the magnification of your refracting telescope?

Two convex lenses can also be used to examine some small object from close up. The thicker lens becomes the objective and the thinner lens the eyepiece, in this case. The setup makes a compound microscope.



G. Place the thicker lens in the taped-down holder on the stiff cardboard. Place the thinner lens in the movable holder. Stand up an open book with fine print as the object. Move the cardboard so that the objective is 7 cm from the print. Move the eyepiece about 25 cm from the objective. Adjust it for clear focus.



- ★ 6-12. Is the image formed by a compound microscope larger or smaller than the object? Is it upside down or right side up?

Some compound microscopes can magnify a tiny object, such as a plant or animal cell, 2000 times. Since light from the small object is spread over a large image, extra light must often be supplied to make the image visible.

You should have noticed that both the refracting telescope and the compound microscope give an upside down image. When a telescope is being used to study stars, planets, the moon, and other celestial bodies, the upside-down image doesn't hurt. But such a telescope wouldn't be very good for watching a football game.

Binoculars are like a pair of refracting telescopes. Each part has two convex lenses. But binoculars also have prisms between the objective and the eyepiece. After the objective has turned the image upside down, the prisms turn it again. That makes it come out upright. Look at Figure 6-2 below.

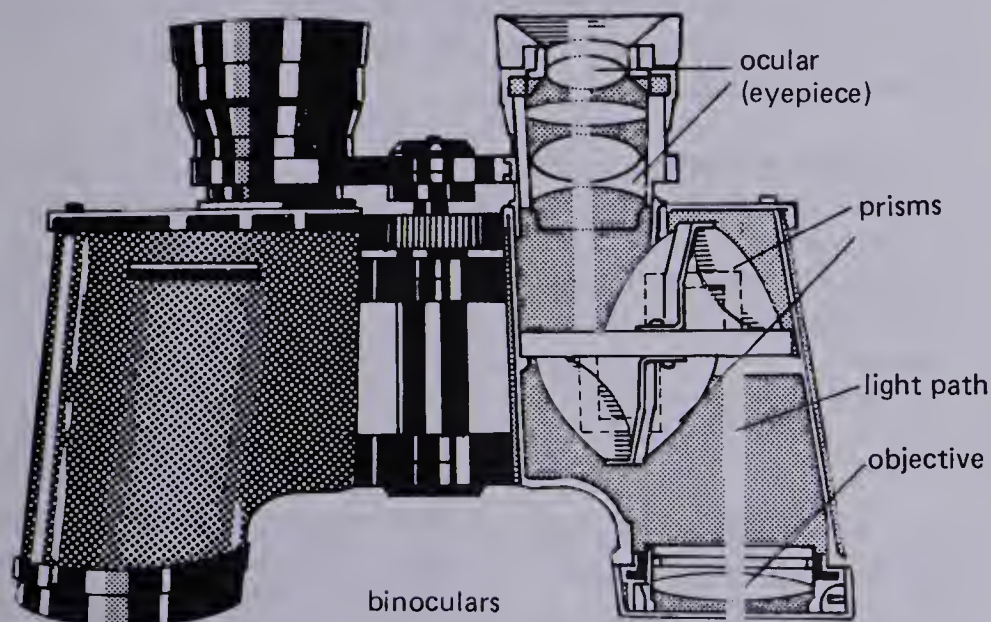
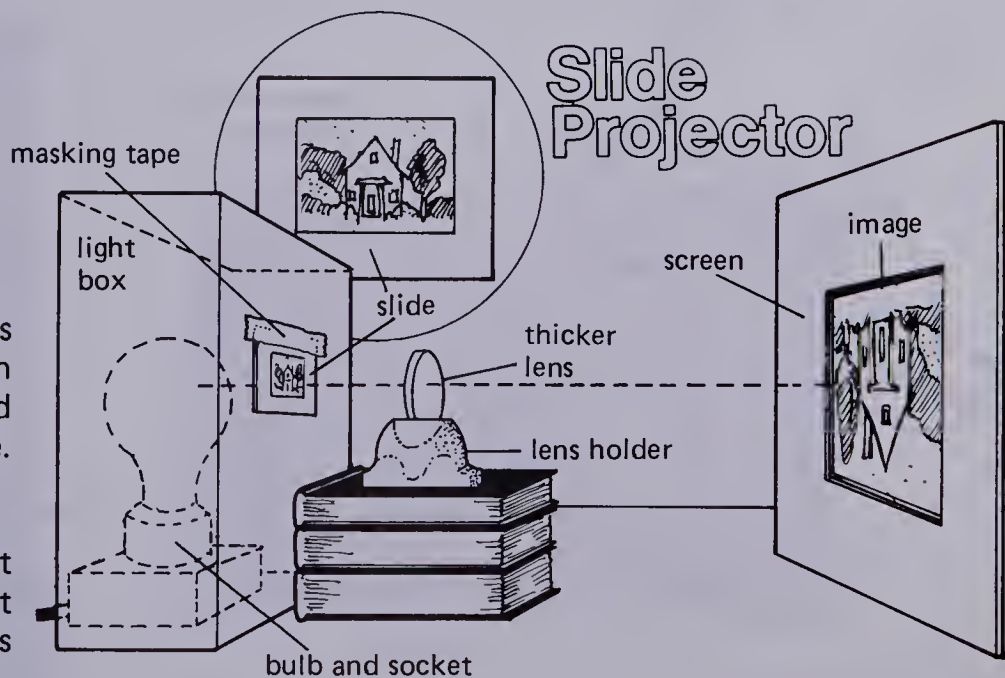


Figure 6-2

Another use of lenses is in projectors — filmstrip, slide, or movie. You can make a simple slide projector with just these few additional materials.

light bulb and socket
light box
35 mm color slide



A. Set up the equipment as shown. Put the thicker lens in the holder. The screen should be about 50 cm from the slide.

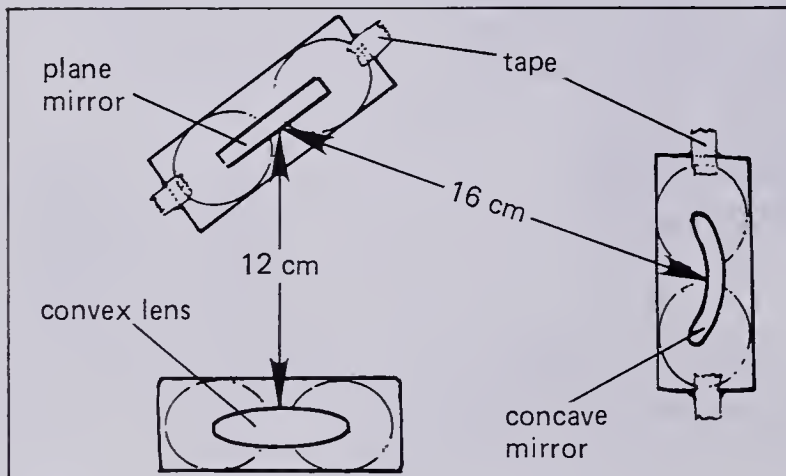
B. Start with the lens about 6 cm from the slide. Move it toward or away for best focus on the screen.

★ 6-13. Is the image formed by a slide projector larger or smaller than the object? Is it upside down or right side up?

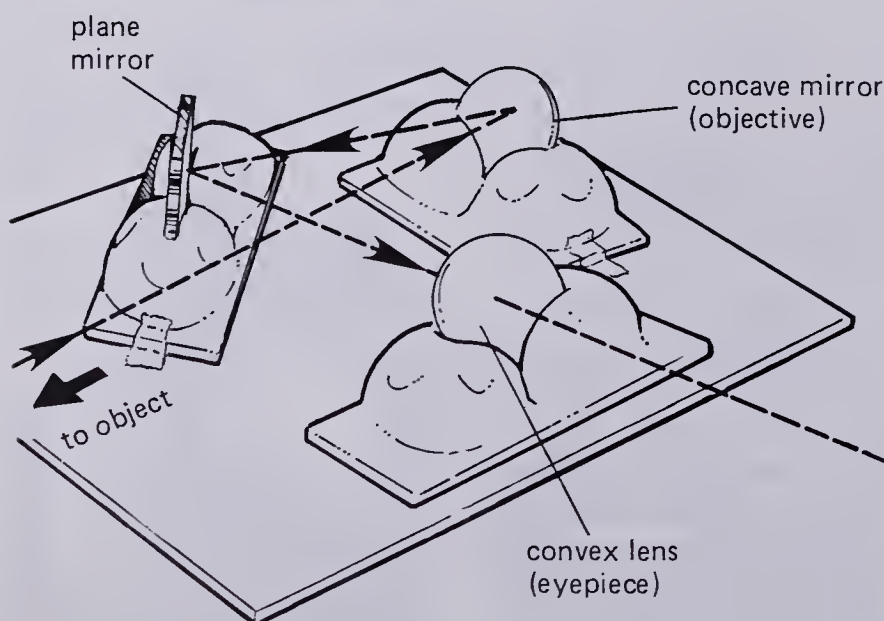
● 6-14. In order to get an upright image on the screen, how must a slide be put into a slide projector?

Many other optical instruments use lenses. One of these is the reflecting telescope. You can put one together using the following materials.

3 egg-carton holders
thinner convex (converging) lens
plane mirror
concave (curved in) mirror
stiff cardboard
tape



A. Put the concave mirror into one of the holders. Tape it to one end of the stiff cardboard. Put the small plane mirror into another holder. Position it as shown from the concave mirror. Tape it to the cardboard. Put the thinner lens into the third holder, and position it as shown.



B. Aim the cardboard so that light from a distant object comes into the concave mirror, as shown. Look through the lens at the plane mirror. Adjust the plane mirror and the lens to get a sharp image.



☆ 6-15. Is the image seen through the lens larger or smaller than that seen by the unaided eye? Upside down or right side up?

The reflecting telescope was designed by Isaac Newton in 1670. The biggest telescopes today are reflectors that use a large concave mirror to gather light from distant stars. Look at Figure 6-3 below.

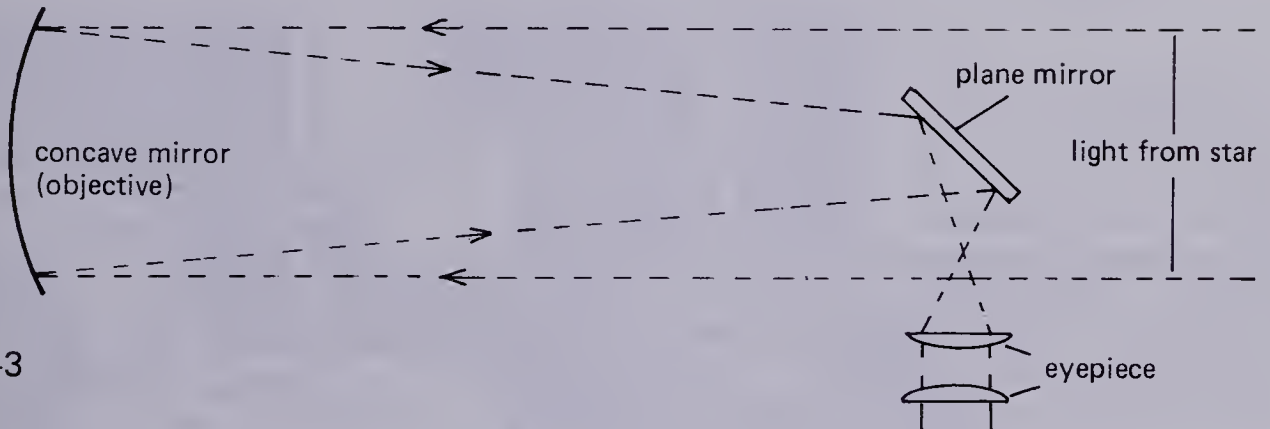
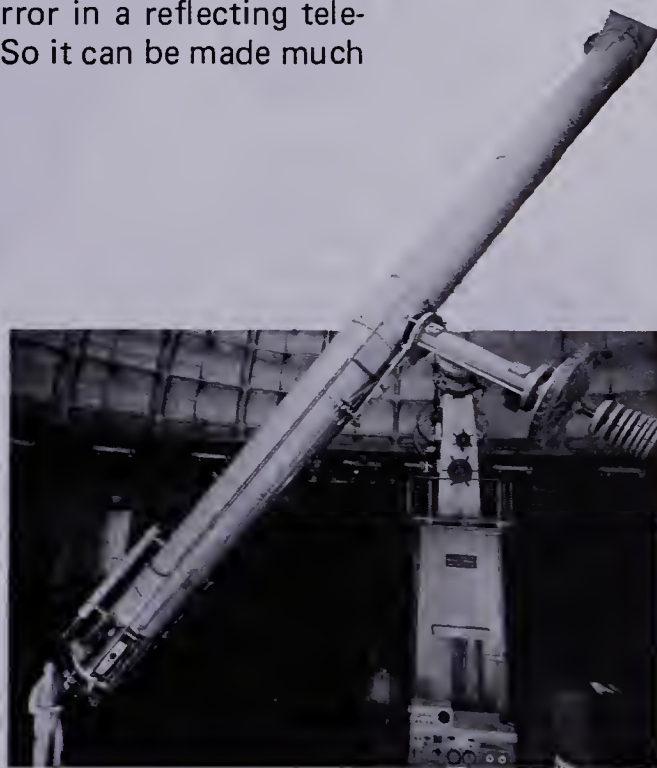


Figure 6-3

Refracting telescopes and reflecting telescopes form the same kind of image. But most modern observatories have reflecting telescopes because they can be made very large to probe deep into space. Other things being equal, the larger a telescope's objective, the more light it can collect. Unlike the objective lens of a refracting telescope, the concave mirror in a reflecting telescope can be supported from the back. So it can be made much larger without the danger of distortion.



Mirror for 120-inch reflecting telescope



36-inch refracting telescope

ACTIVITY 7: MIRROR, MIRROR

When you look in a mirror, you don't actually see yourself. What you see is an image of yourself. The image is formed by light rays that strike the mirror and reflect into your eyes.

Originally, the light rays come from the sun or some other source such as a light bulb. They bounce off you. Then they bounce off the mirror.

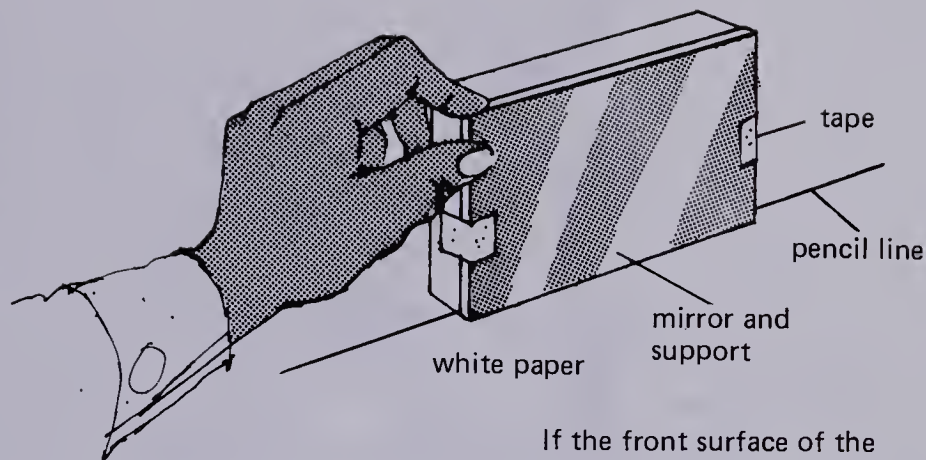


Mirrors can be made with surfaces that curve out or curve in. As you'll see later in this activity, such mirrors have special properties and special uses. But ordinary, everyday mirrors generally have flat surfaces. Another name for them is *plane* mirrors.

In a famous story, a girl named Alice stepped through a mirror. (She called it a *looking glass*.) She entered a strange world. That's not possible in real life. But it is possible to investigate some of the interesting properties of mirror images. Try it. First, you'll need to locate an image in a mirror. You'll need the following materials.

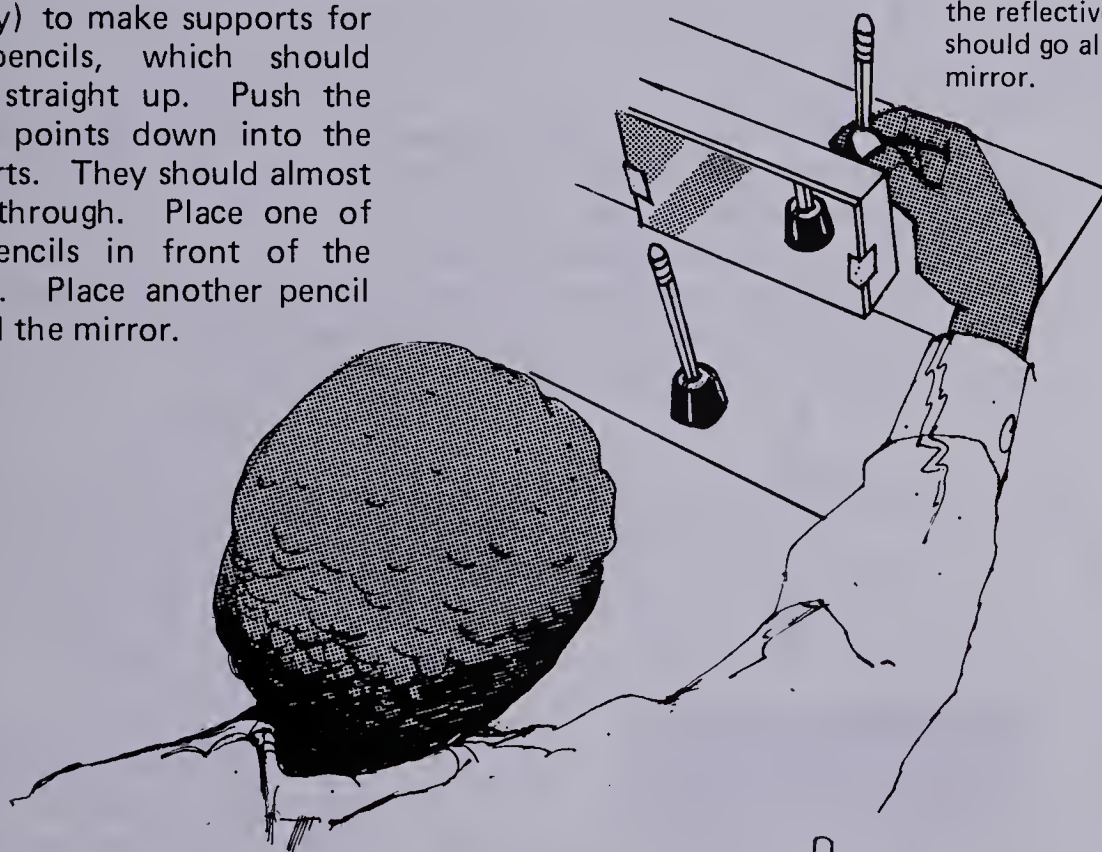
- 3 pencils
- 3 one-hole stoppers (or lumps of modeling clay)
- plane mirror with support
- sheet of white paper
- metric ruler
- protractor

A. Draw a straight line down the center of the white paper. Stand the mirror on the paper with its reflecting surface on the center line.

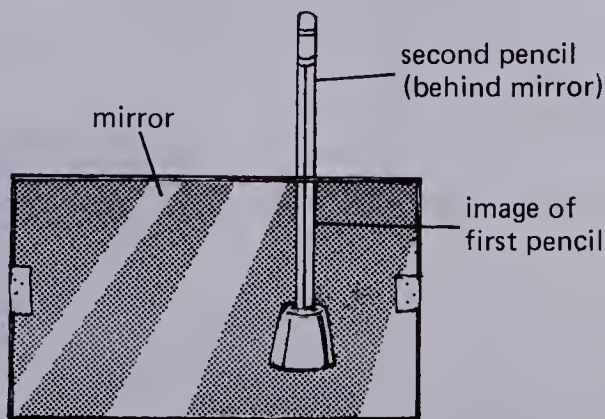


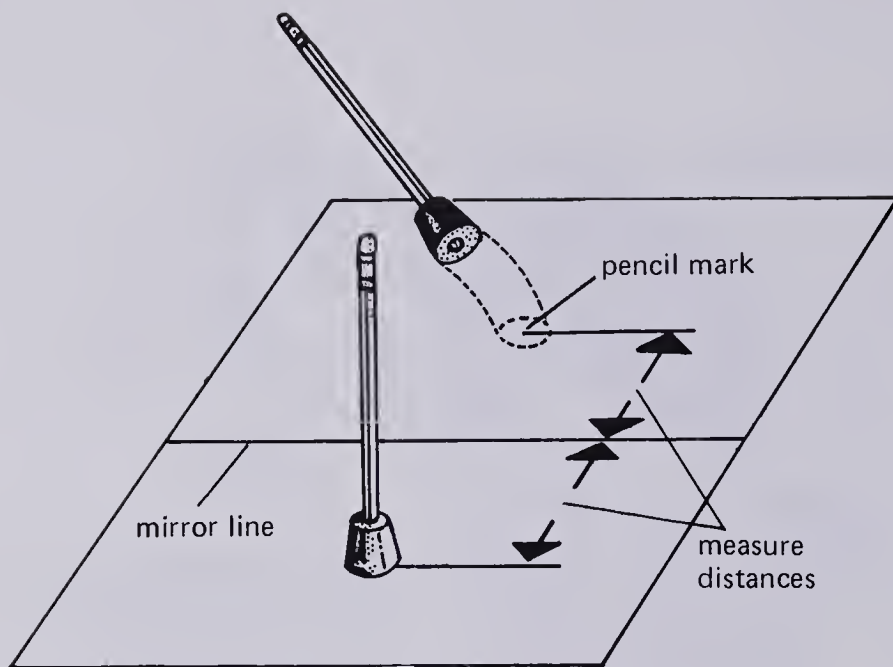
B. Use the stoppers (or lumps of clay) to make supports for the pencils, which should stand straight up. Push the pencil points down into the supports. They should almost poke through. Place one of the pencils in front of the mirror. Place another pencil behind the mirror.

If the front surface of the mirror is the reflecting surface, the line should be even with the front. If the rear surface is the reflective surface, the line should go along the rear of the mirror.



C. Line up the second pencil so that it stays in line with the image of the first pencil no matter what direction you look toward the mirror. Move your head back and forth as you line up the second pencil.





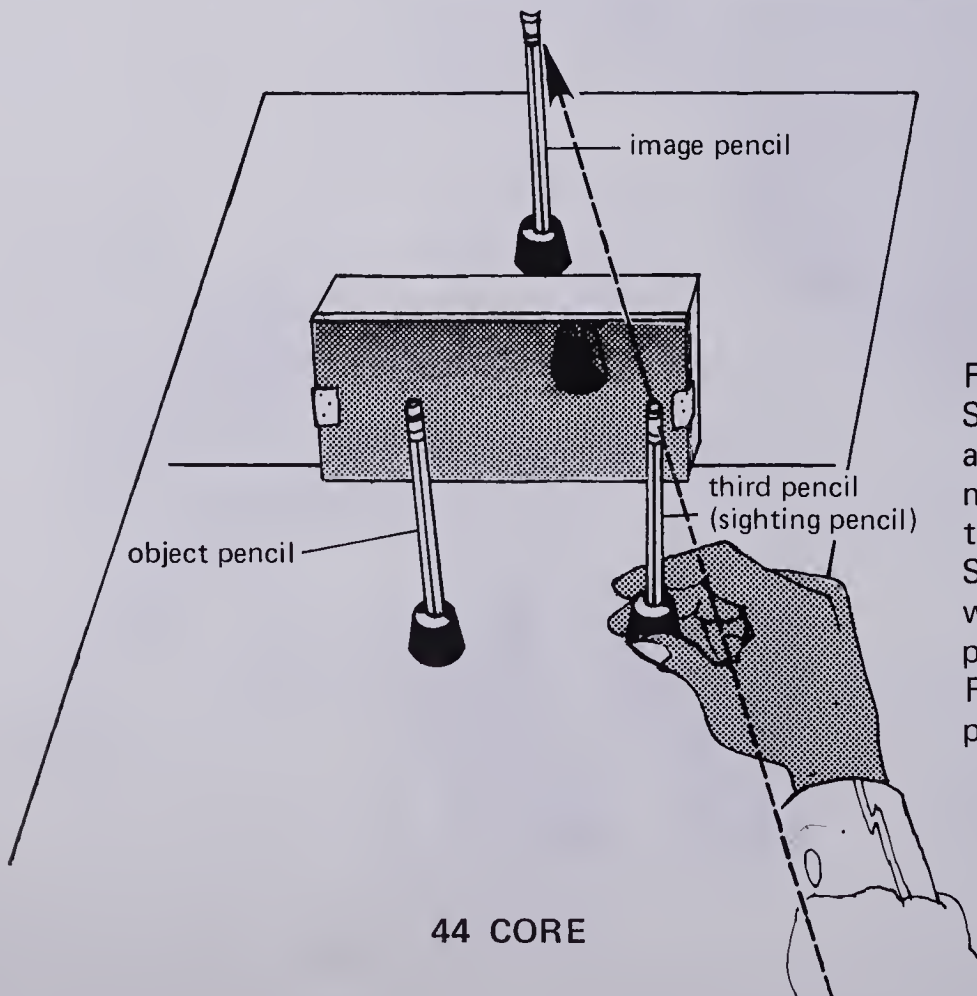
D. Carefully remove the mirror, but leave both pencils where they are. Holding each pencil in place, push straight down to make a mark on the paper. Then measure the distance of each pencil mark from the mirror line.

E. Repeat Steps B, C, and D several times, putting the front pencil at different distances from the mirror each time.

- 7-1. On each trial, were the two pencil marks different distances from the mirror line or the same distance?

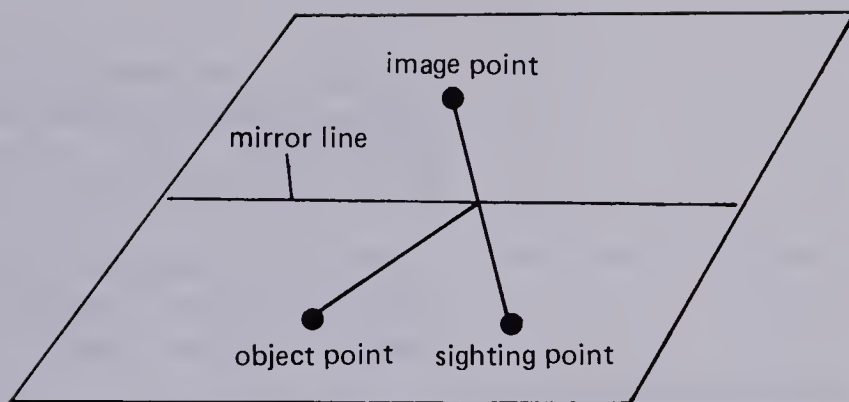
Your experiment with the pencils has shown three interesting and important things about mirror images. First, the image in a vertical plane mirror is right side up. Second, it seems as far behind the mirror as the object is in front of it. Third, the image seems as large as the object would appear at that distance.

Another property of mirror images relates to the angles at which light rays approach and leave the mirror.

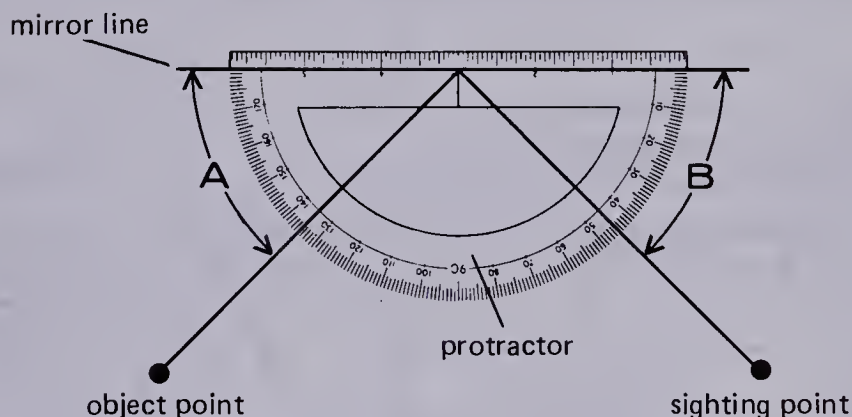


F. Turn the paper over. Repeat Steps A, B, and C. Once again, you have located a mirror image. Now's the time to use the third pencil. Sight along it. Line it up with the image. Mark the positions of all three pencils. Remove the mirror and the pencils.

G. Draw a straight line connecting the point of the image pencil and the point of the sighting pencil (the third pencil). From the point where this line crosses the mirror line, draw a straight line to the point of the object pencil.



H. Look at the lines you have drawn to the mirror line from the pencil points. They form angles with the mirror line. Label these angles *A* and *B*, as shown. Then measure them with the protractor.



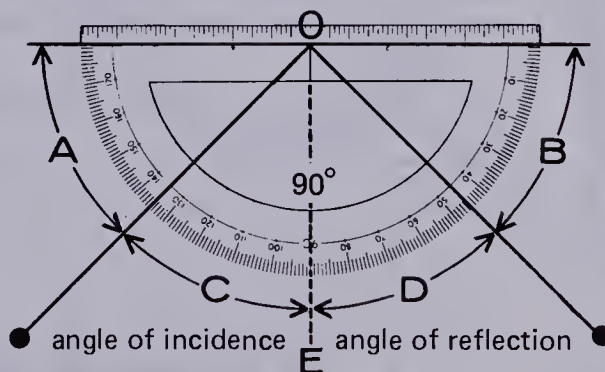
If you're having trouble with the protractor, read "Resource Unit 8: Using Protractors" for help.

● 7-2. How do Angles A and B compare?

The angles should be equal. If they are more than a degree or so different, you should repeat Steps F, G, and H.

Like you, scientists compare the incoming and outgoing angles of light rays. But they use a different pair of angles for this purpose. So can you.

I. Using the protractor, draw a perpendicular — a 90° angle — forward from the mirror line at Point O (where the lines you drew earlier crossed the mirror line). The perpendicular is shown here as Line OE. Then use the protractor to measure the angles shown as C and D.



★ 7-3. When light reflects from a plane mirror, how does Angle C (the angle of incidence) compare with Angle D (the angle of reflection)?

Angle C, the angle of incidence, is the angle between the incoming light and a perpendicular to the reflecting surface.

- 7-4. Angle D is the *angle of reflection*. Define that term.

The law of reflection of light states that the angle of incidence equals the angle of reflection. This law helps explain how mirrors form images. Look at Figure 7-1 below.

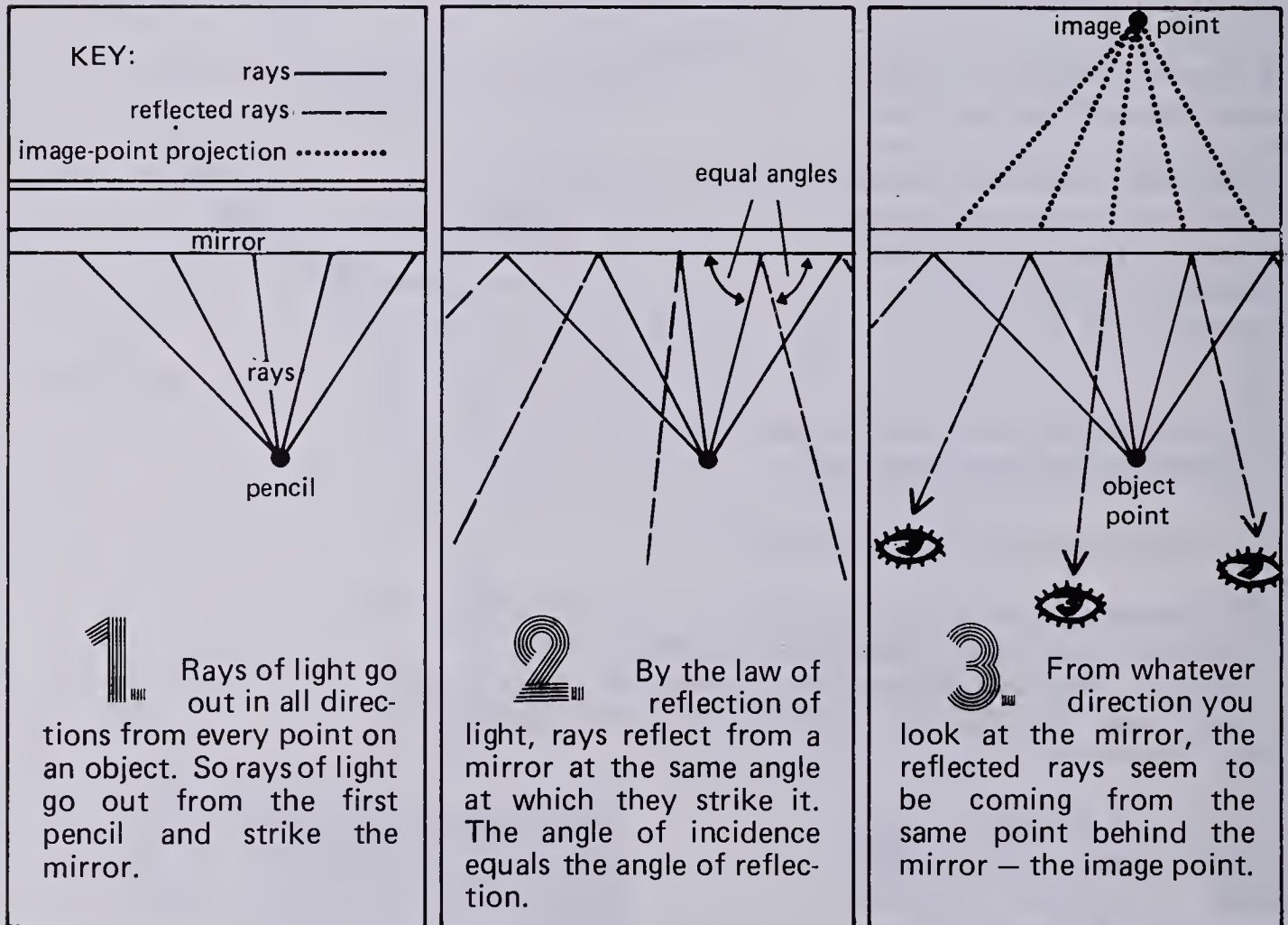
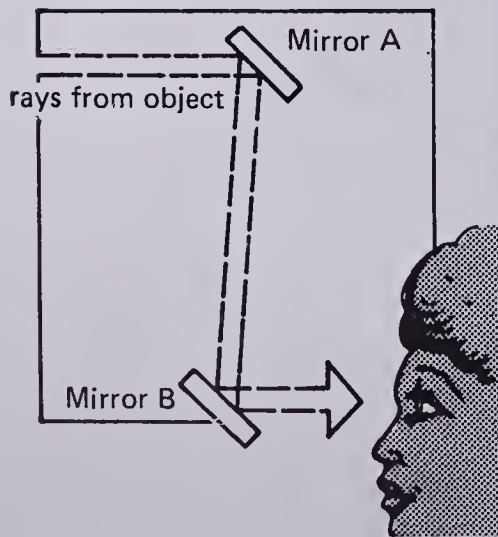


Figure 7-1



- ☆ 7-5. When an object is reflected in a plane mirror, where do the rays of light appear to be coming from?

Combinations of plane mirrors are used in range finders, periscopes, sextants, and other optical devices. But not all mirrors are plane.

Mirrors can also be curved in — concave — or bulged out — convex. The rays reflected in curved mirrors follow the same rules as those reflected in plane mirrors. Curved mirrors have many uses. Look at Figure 7-2 below.

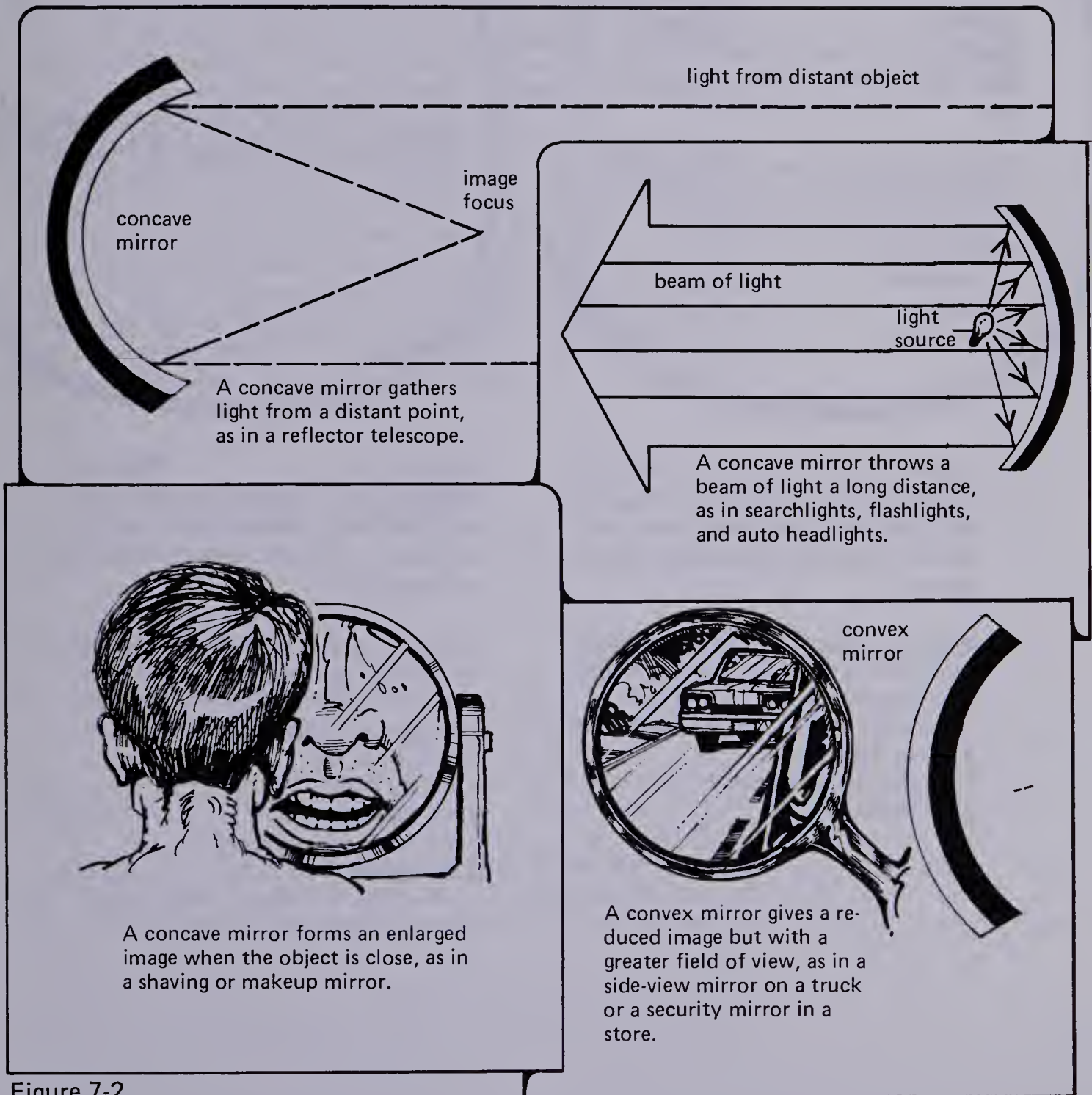


Figure 7-2

☆ 7-6. Is the image formed by a convex mirror larger or smaller than the object? Upside down or right side up?

ACTIVITY 8: PLANNING

Activity 9

Page 49

Objective 9-1: Using the wave model of light, explain what is meant by *refraction*.

Sample Question: When refraction of a wave occurs, which of the following wave properties remains unchanged?

- A. Wavelength
- B. Frequency
- C. Speed
- D. Distance

Advanced

Activity 10

Page 55

Objective 10-1: Explain how image size and image type are related to the location of the object and the focal length of the lens.

Sample Question: Where must the object be located in order for a convex lens to form a virtual image?

- A. Between the lens and the focal point
- B. At the focal point
- C. Beyond the focal point
- D. At the lens

Activity 11

Page 63

Objective 11-1: Describe how illumination varies with distance, and be able to recognize the common units for measuring illumination.

Sample Question: A point-source ceiling light shines on the floor. Then it is raised until it's twice as far from the floor as it was. How is illumination of the floor affected?

- A. It's cut in half.
- B. It's doubled.
- C. It's reduced to one-fourth.
- D. It's tripled.

Answers: 9-1. B; 10-1. A; 11-1. C

ACTIVITY 9: REFRACTION

You have already seen that light doesn't always travel in straight lines. It bends, for instance, when passing through a glass lens. In fact, almost any time light passes from one medium into another, you can observe the phenomenon of light paths bending. This bending is called *refraction*.

This activity explains how refraction works and the effects of refraction.

So far you've been using a ray model. To investigate refraction, you need to think about light in terms of a *wave model* — waves like those of the ocean or a large lake. Light can be shown to have, among other things, a wave nature.

The distance between the crests or troughs of two successive waves is called the *wavelength*. (Actually, it doesn't have to be between crests or troughs — just between the same points on two consecutive waves.) The interval of one wavelength is sometimes called a *cycle*. Look at Figure 9-1 below.

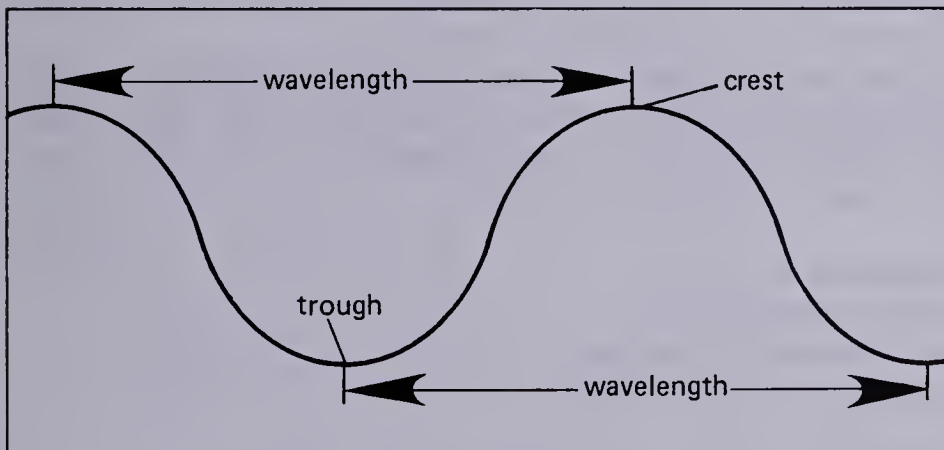


Figure 9-1

The rate at which a wave moves through its medium is called the wave's *speed*. Speed is expressed in metres per second. It measures the distance traveled in a second by any point on the wave.

Another property of waves is called *frequency*. It counts the number of wave crests (or number of cycles) per second that pass through a fixed point. Frequency used to be measured in cycles per second (cps). Today, one cps is called a *hertz* (Hz).

Although speed and frequency are related, two wave patterns can have the same speed and different frequencies — and vice versa. Look at Figure 9-2 (page 50). The two wave patterns have the same speed, but B has double the frequency of A.

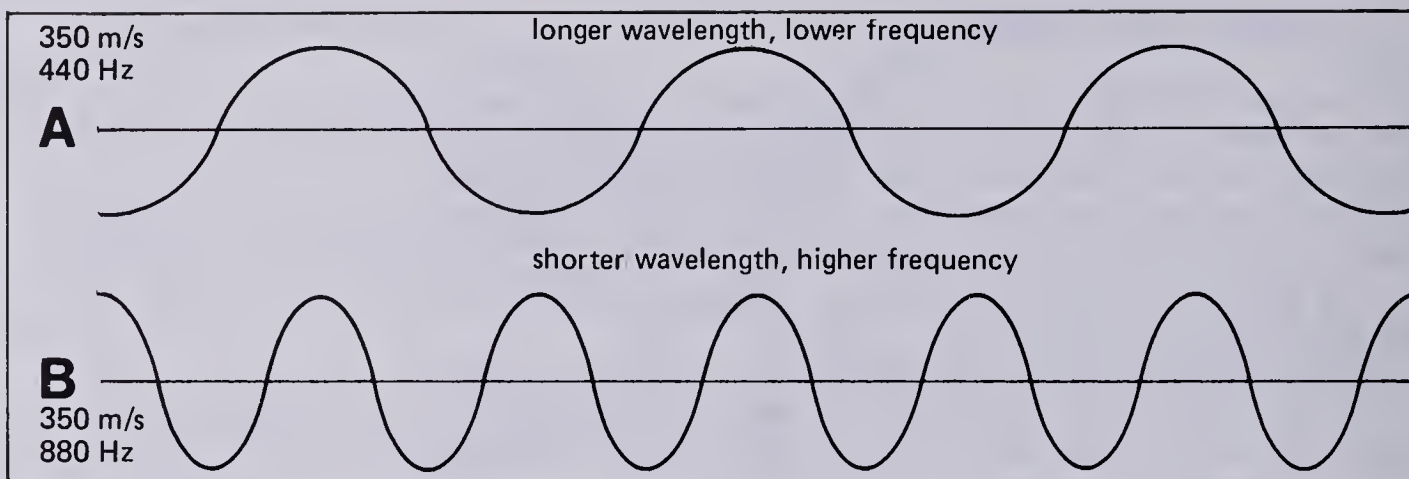


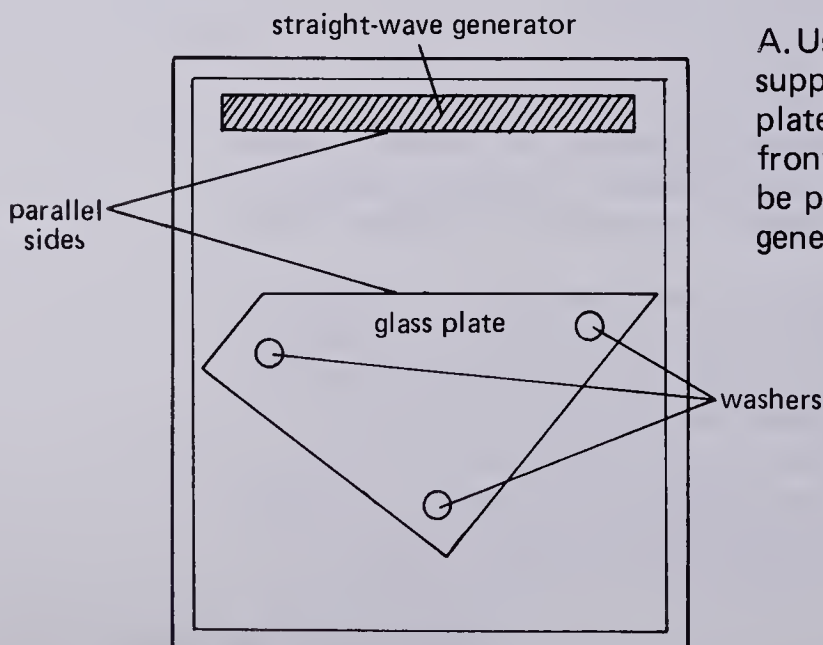
Figure 9-2

If speed is kept the same as in Figure 9-2 above, wavelength varies inversely with frequency. That is, the longer the wavelength, the lower the frequency. And the shorter the wavelength, the higher the frequency.

A wave's speed is affected by properties of the medium. Light waves, for example, travel slower in a dense medium such as water than in a thin medium such as air.

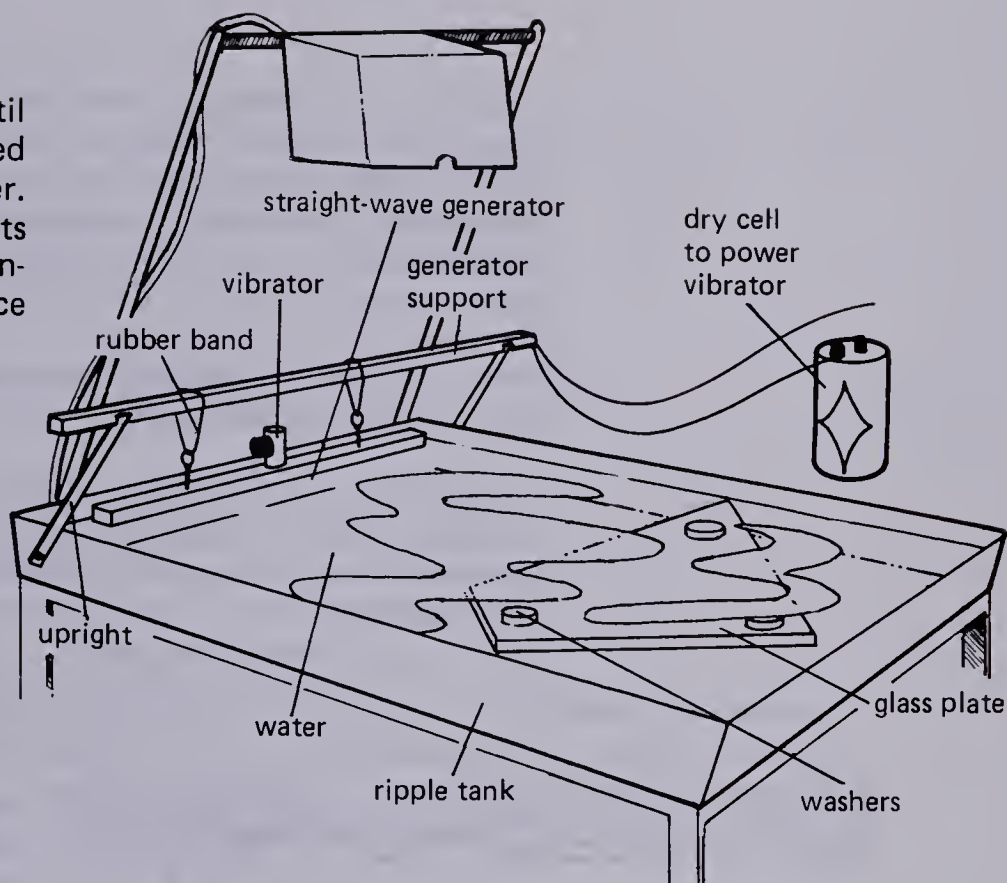
Surface waves on water — that is, waves of water itself — vary in speed according to how deep the water is. It's as if each depth were a different medium. Use this idea in the following investigation. You'll need these materials.

ripple tank kit
glass or plastic plate
several washers or pennies
2 wooden or paraffin blocks

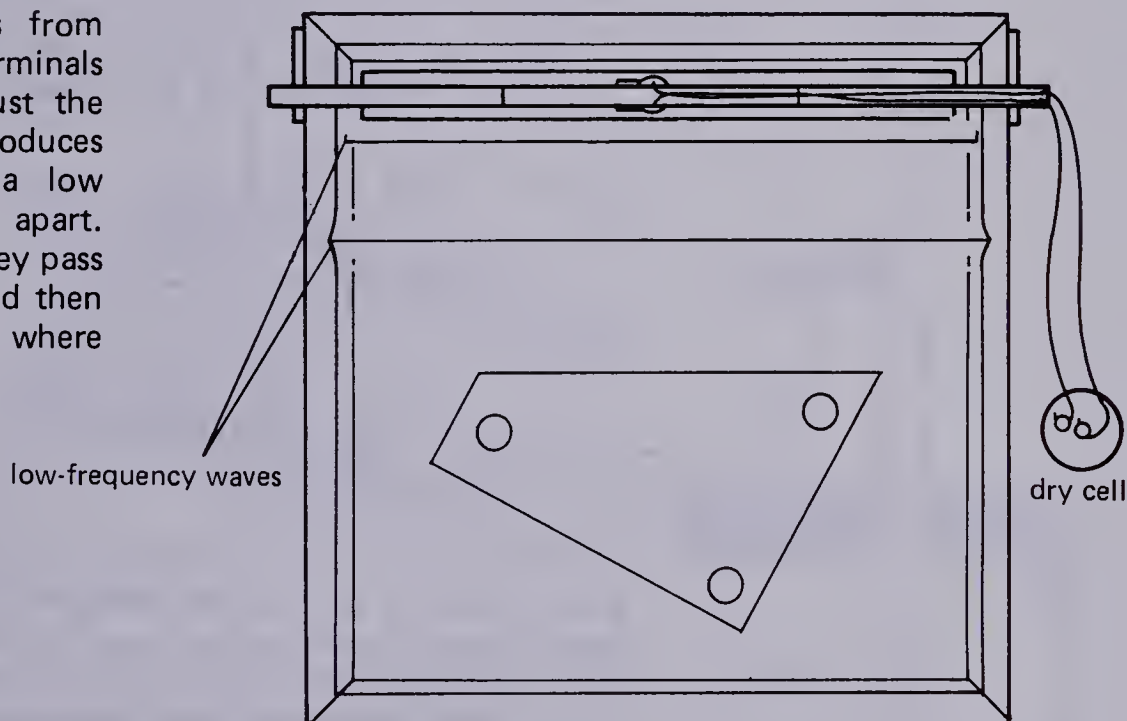


A. Use washers or pennies to support the glass or plastic plate in the ripple tank. The front edge of the plate should be parallel to the straight-wave generator.

B. Add water to the tank until the plate is barely covered with a thin layer of water. Adjust the upright supports so that the straight-wave generator just touches the surface of the water.



C. Connect both wires from the vibrator to the terminals of the dry cell. Adjust the vibrator motor so it produces straight waves with a low frequency — waves far apart. Observe the waves as they pass over the deep water and then over the shallow water where the plate is.



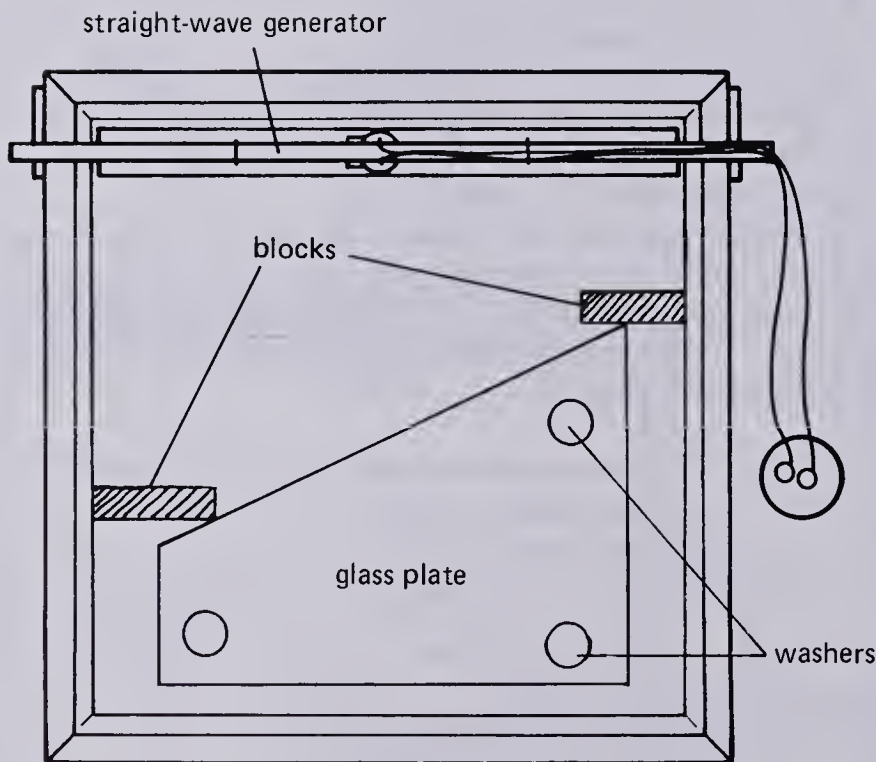
- 9-1. Describe any differences you saw between the waves over the two areas.

Speed, frequency, and wavelength are interrelated features of a wave pattern. Speed (v) equals frequency (f) times wavelength (λ). This can be expressed in a formula as $v = f\lambda$.

In your investigation, the frequency of the vibrator was constant — it didn't change. The vibrator created the waves. Therefore, the frequency of the water waves remained the same throughout. But, as you observed, the wavelength — the distance between wave crests — did change. It got shorter in shallow water.

★ 9-2. How did the speed of the wave in shallow water compare with its speed in deep water?

So far in your investigation, the front of each wave has been parallel to the front edge of the plate as the wave front moved over the plate. Change the situation in the ripple tank, and see what happens.



D. Disconnect the vibrator from the cell. Turn the glass plate about 30° so that the waves will strike it at an angle. Place the blocks as shown to remove unwanted parts of each generated wave. Reconnect the vibrator to the cell. Don't change the frequency.

● 9-3. Describe at least two things you saw happen when the waves traveled from the deep water into the shallow water.

The bending of waves in this fashion is called *refraction*. Much the same thing occurs when light gets bent passing from the air into a glass lens.

● 9-4. Try to account for the changes you noted in your answer to Question 9-3 above. [Hint: See your answers to Questions 9-1 (page 51) and 9-2 above.]

Perhaps you were able to suggest that a change in the speed of the wave caused the refraction. Now look at how a wave model for light supports this explanation. Think of the wave front of a light wave as if it were a water wave. Suppose one end of the wave gets slowed down relative to the other end. Then, as a result, this part of the wave front will change direction. That's roughly how it works. Only the wavelength and speed of light change as the light waves pass into a different medium. The frequency will be unchanged. Look at Figure 9-3 below.

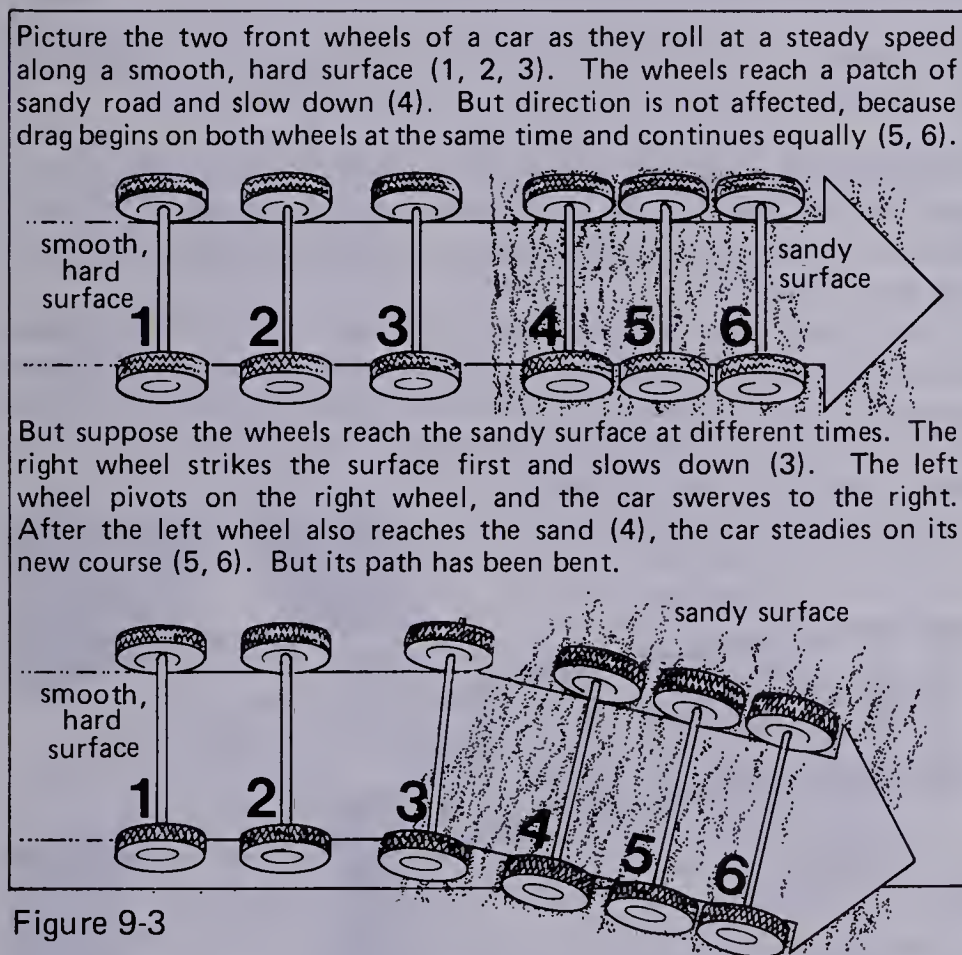


Figure 9-3

- 9-5. In Figure 9-3 above, does a wheel in sand move faster or slower than a wheel on smooth ground?

Light waves often seem to behave just like the wheels of the car. When light moves from air into glass, it slows down. And when it leaves the glass, it speeds up.

If light strikes a glass surface at a 90° angle, no refraction occurs. The beam passes straight through without bending, as shown in Figure 9-4.

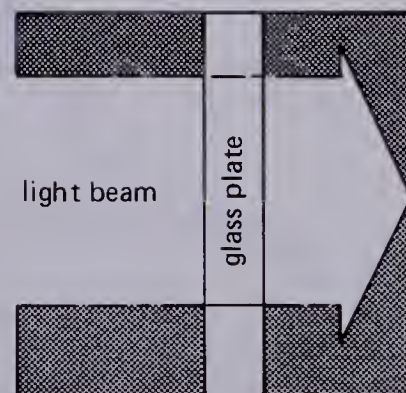


Figure 9-4

- 9-6. Using the terms of the wave model, explain Figure 9-4.

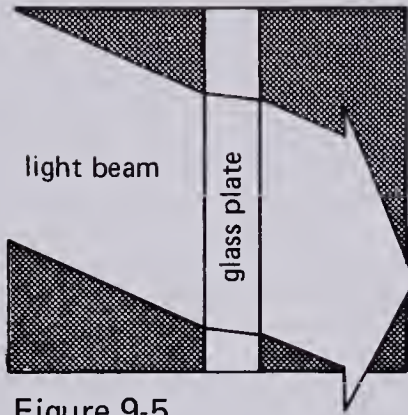


Figure 9-5

But suppose light strikes a glass surface at an angle other than 90° . Then it bends. The slanting beam of light is refracted. And if the sides of the glass plate are parallel, the beam bends back to its original direction when it leaves the glass. That's what happens when light passes through a window pane. If the glass is free of irregularities, the light waves go through with the merest wiggle, as in Figure 9-5.

★ 9-7. In terms of the wave model, why does a slanting beam of light bend when passing from air into glass?

● 9-8. When a slanting beam of light leaves a pane of glass, in what direction does it bend? (Hint: Look at Figure 9-5.)

Suppose the wheels of a car pass through a sandy area whose edges are not parallel. If the wheels cross the edges at a slant, their path will bend both when they enter the sandy area and when they leave it.

In the same way, a light beam will bend twice when passing through a double convex lens. Two bends through a window pane cancel each other out. But the two bends through a double convex lens are in the same direction. Their effects are combined. Look at Figure 9-6 below.

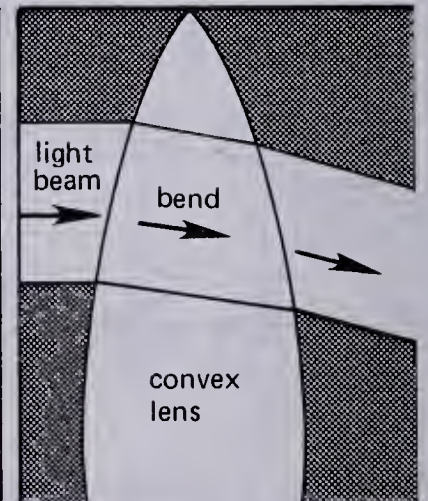
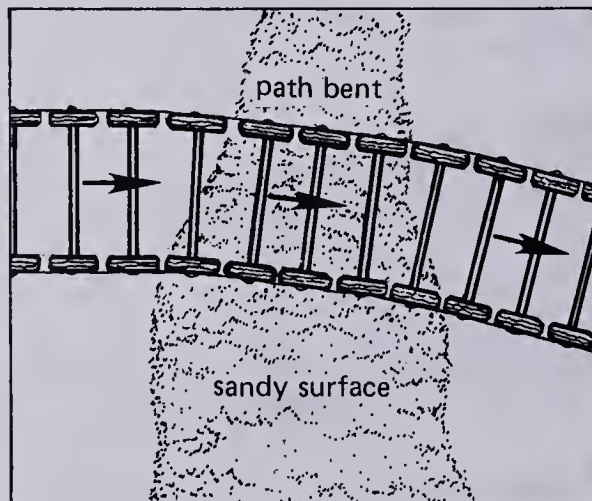


Figure 9-6

● 9-9. In Figure 9-6 above, which way does the light beam bend when leaving the lens?

Light refraction — the bending of the light path as it passes from one medium into another — accounts for many everyday phenomena. It's this property of light that makes lenses work, produces colorful rainbows, and causes water to appear shallower than it really is.

ACTIVITY 10: LENS IMAGES

You have already learned that a convex (converging) lens can focus an image on a screen. It does this by refracting the light rays. At this very moment, the convex lens in your eye is focusing an image of this print on your retina. In doing so, your eye's lens is refracting the rays of light that are bouncing off this page.

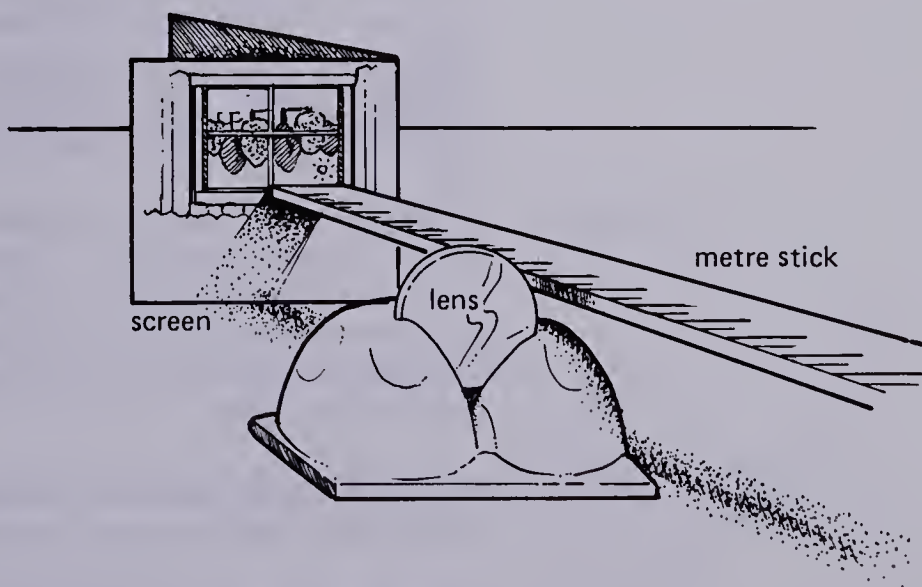
The lens of your eye is adjustable. It accommodates to focus on objects at varying distances. But unlike the lens of your eye, most lenses have a fixed shape. How does the position of an object and the focal length of the lens affect the image that is formed? To find out, try this investigation. You'll need the following equipment.

2 double convex lenses, one thicker and more curved than the other
egg-carton lens holder
white cardboard screen
metre stick or ruler
candle
safety matches

A. In your notebook, make a table similar to this one.

LENS	FOCAL LENGTH (cm)
Thinner and less curved	
Thicker and more curved	

B. Find the focal length of each of the lenses by focusing a sharp image of a distant object on the screen. Then, measure the distance from the center of the lens to the screen. Record these values in cm in the table in your notebook. (If you need help finding focal length, refer to Activity 6.)



- 10-1. Were the images on the screen larger or smaller than the object? Upright (right side up) or inverted (upside down)?

There's another thing to know about the image of the distant object that is formed on the screen. It's called a *real image*. *Real images* are defined as those that can be formed on a screen. And with a real image, rays of light actually converge to a focus. Look at Figure 10-1 below.

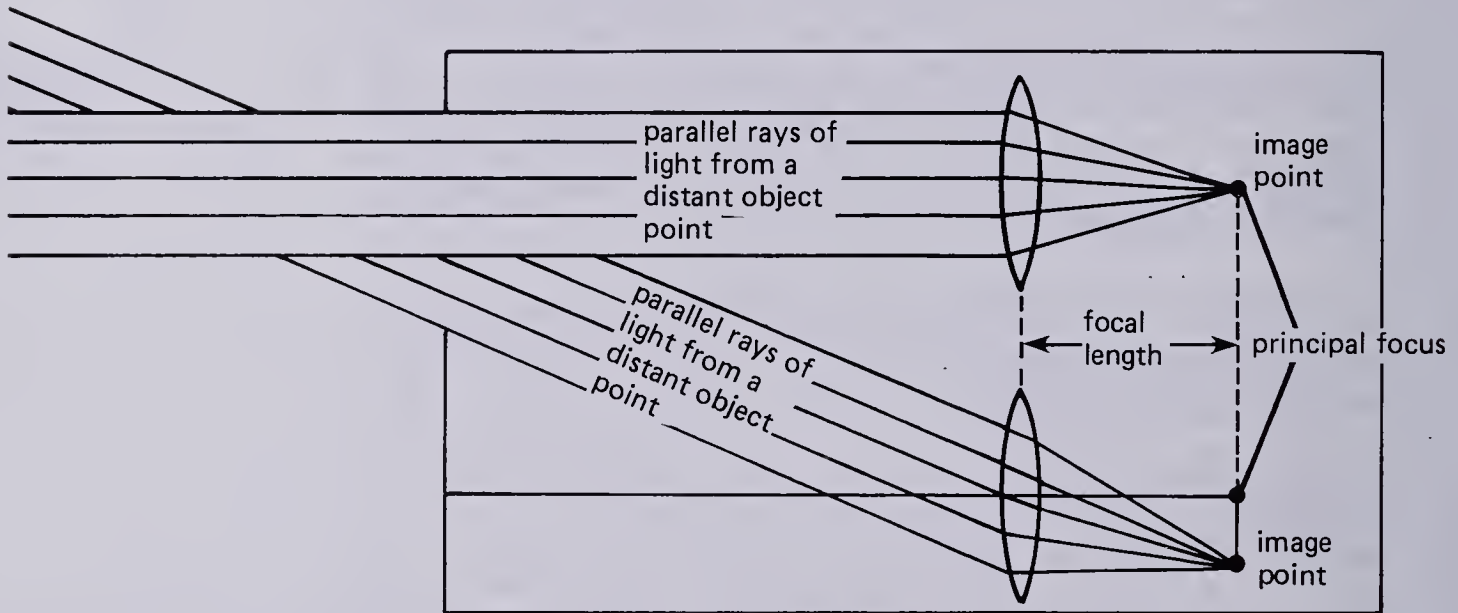


Figure 10-1

Notice that the parallel rays can enter the lens at any angle. That won't change the focal length, which is fixed for each lens.

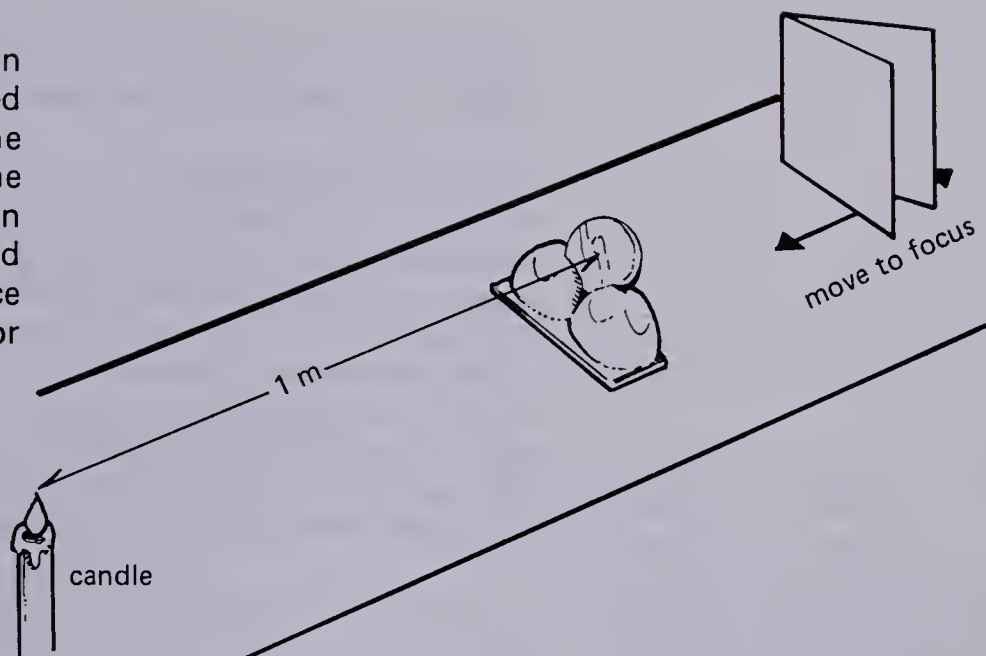
One spot at a focal length's distance from the lens is called the *principal focus*. That's the place where the image point will be if the parallel rays are exactly perpendicular to the plane of the lens.

You may be wondering about the use of the term *parallel rays*. If rays come from a point, they can't be truly parallel. They will always diverge a little. But, for practical purposes, rays are considered parallel if their angle of divergence is less than one degree. With the object 5 m from the lens, the angle is less than half a degree.

- 10-2. With which lens is the principal focus closer to the lens — the thinner and less curved or the thicker and more curved lens?

Let's continue the investigation of the effect of the position of an object and the focal length of a lens on the formed image. The focal length of a lens doesn't change, so you can concentrate on the position of the object.

C. Place either convex lens in the lens holder. Put a lighted candle about 1 m from the lens. Focus the image of the candle's flame on the screen by moving the screen back and forth. Measure the distance from the lens to the screen for a focused image.



- 10-3. What was the lens-to-screen distance?
- 10-4. Was the distance greater or less than that with the object 5 m from the same lens in Step B?

This step of your investigation should have told you something about image location when the object moves toward the lens. But it still couldn't tell you much about the effect of object position or image size.

- 10-5. Was the image upright or inverted?

Perhaps the ray model might help you to see how an image of an object is formed. Figure 10-2 below shows a ray diagram. (If you have forgotten the ray model, refer to Activity 2.)

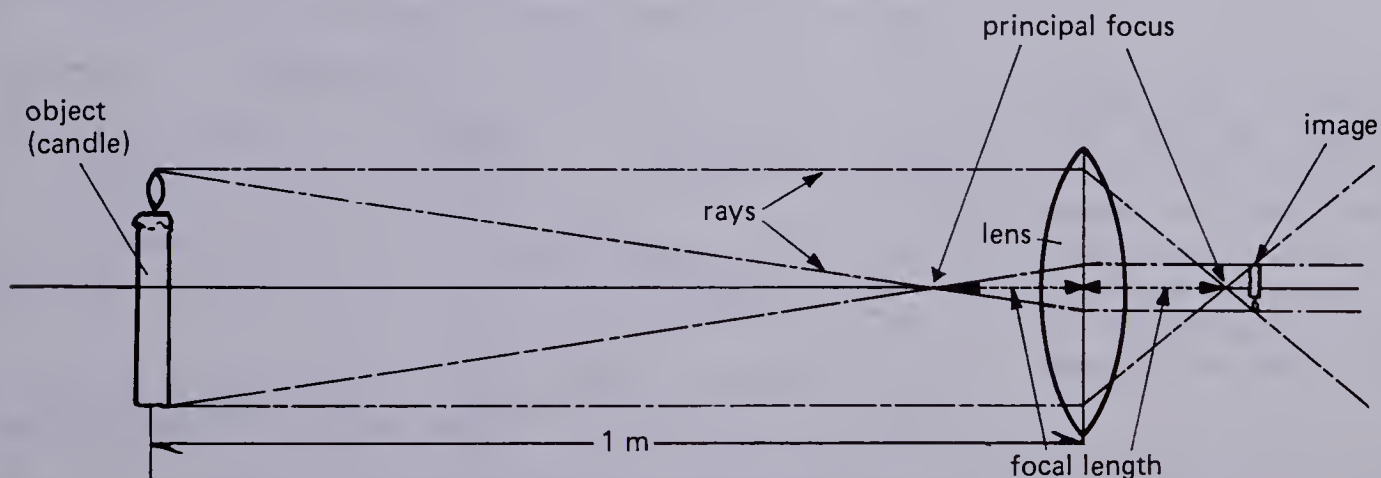


Figure 10-2

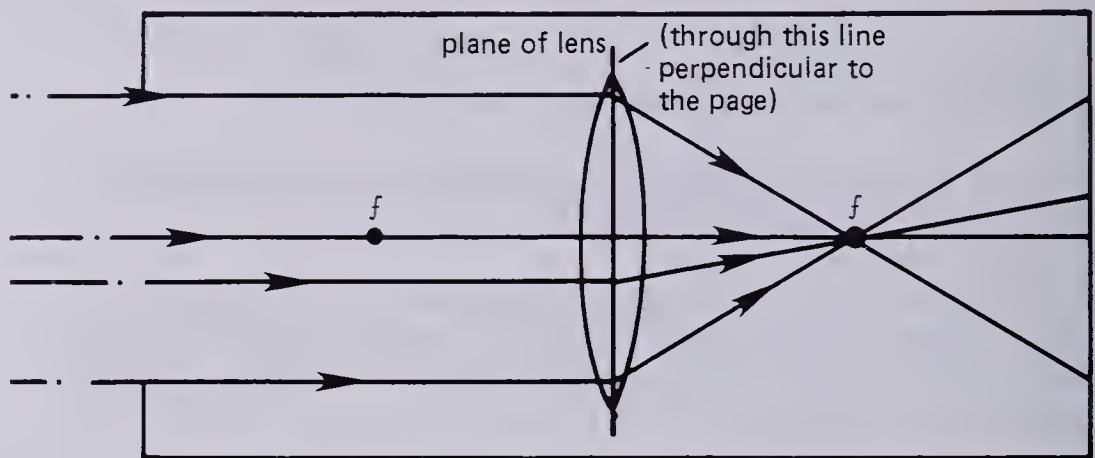
Notice that the image forms farther away from the lens than the principal focus in the diagram. And it is inverted.

• 10-6. Is the image real?

Remember that a real image is one that can be focused on a screen and that is formed by rays of light coming together. The ray diagram shows that this happens.

The ray diagram should be a big help in understanding how light behaves as it passes through a lens. Images are formed when light rays are focused by the lens. Here are two rules that will help you draw a ray diagram. All you have to remember is that any convex lens has a principal focus, f , on each side of the lens.

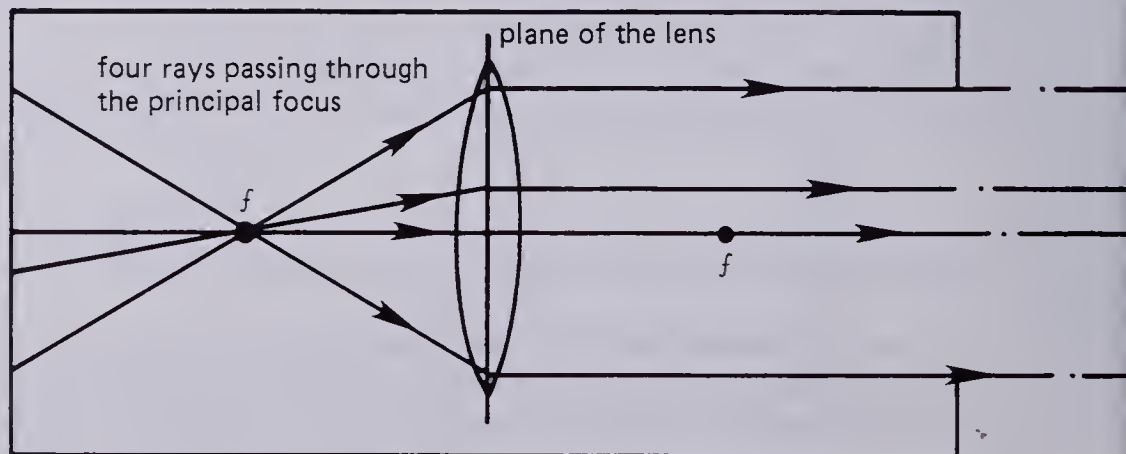
RULE 1: Any ray that passes through the lens perpendicular to the plane of the lens will also pass through the principal focus on the other side of the lens.



• 10-7. The procedure for finding the focal length of a lens is illustrated in Figure 10-1 (page 56). How does Rule 1 compare with it?

Rule 2 is just the reverse of Rule 1. It tells what happens to a ray that passes through the principal focus.

RULE 2: Any ray that passes through the principal focus of a lens and then passes through the lens will continue on the other side perpendicular to the plane of the lens.



- 10-8. If the four rays are perpendicular to the plane of the lens, what is their relation to one another?

Let's use the two rules to predict the appearance, location, and size of an image when the appearance, location, and size of the object is known. In Figure 10-3 below, an upright candle is located at a point twice the focal length from the lens. A step-by-step ray diagram locates the image.

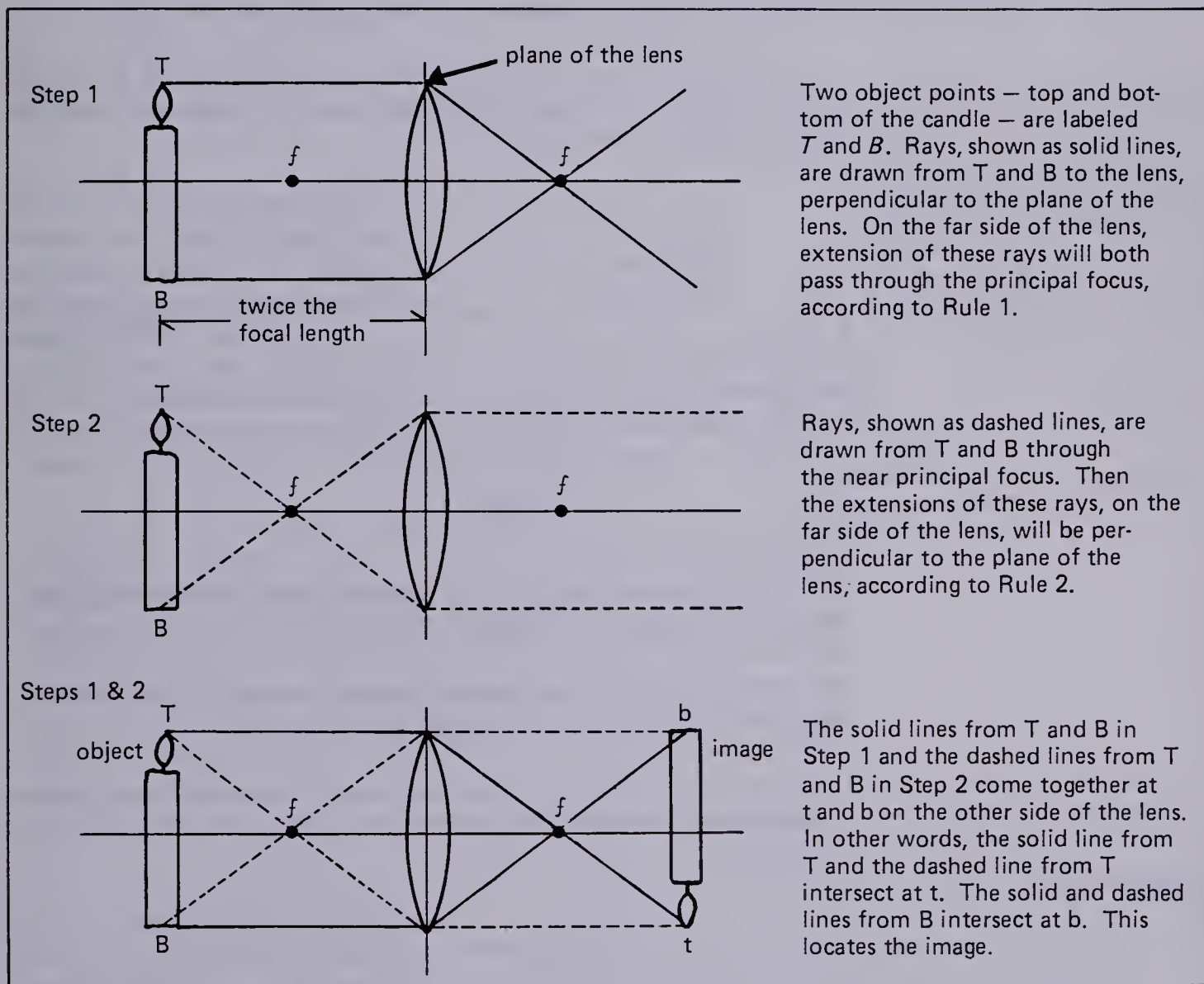


Figure 10-3

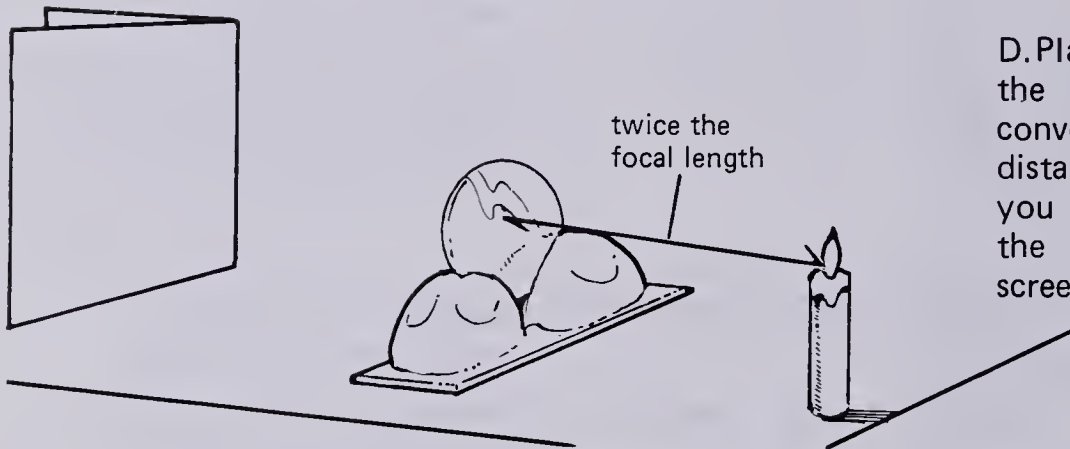
- 10-9. How can you be sure that t is the image point of T , rather than some other point?

Examine the image to see how it compares in appearance and size with the object.

☆ 10-10. With an object at twice the focal length from a convex lens, will the image be upright or inverted? Larger, smaller, or the same size as the object?

- 10-11. From the diagram, is it a real image? That is, do rays from object points come together at the image?
- 10-12. How does the distance of the image from the lens seem to compare with the distance of the object from the lens?

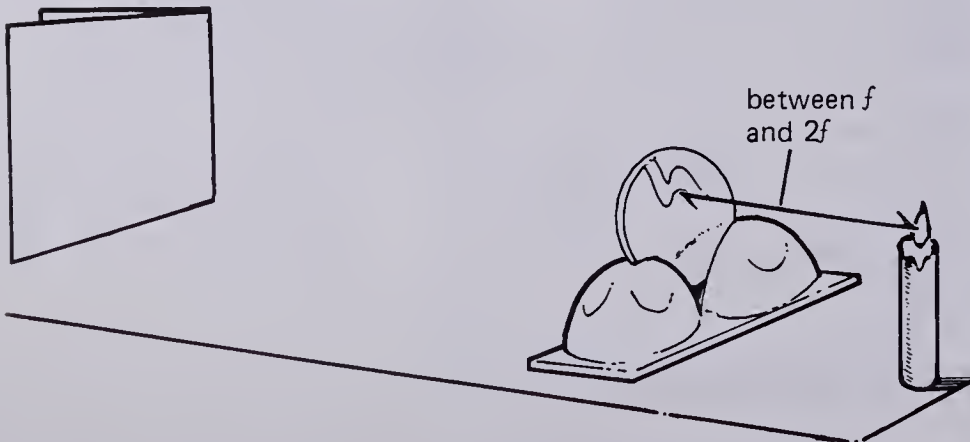
The ray diagram seems to tell you a great deal about the image of an object. Let's see if it works out the same way with an actual object — the candle.



D. Place a lighted candle twice the focal length from either convex lens. Be sure that the distance is correct for the lens you are using. Then, focus the image by moving the screen back and forth.

- 10-13. How did the actual image compare with the predictions from the ray diagram (Questions 10-10, 10-11, and 10-12 above)?
- 10-14. What do you predict about the image if the object is moved closer still to the lens (between f and $2f$)?

That was a tough prediction to make. You could have drawn a ray diagram to know how it would be. But you can try it with the candle.



E. Place a lighted candle at a distance between the focal length and twice the focal length from either convex lens. Be sure the distance is correct for the lens you are using. Focus the image on the screen.

- ★ 10-15. Describe the image for size, appearance, and location when the object is between f and $2f$ from the lens.

Figure 10-4 below shows a ray diagram of an object between f and $2f$ from a convex lens. Follow the steps.

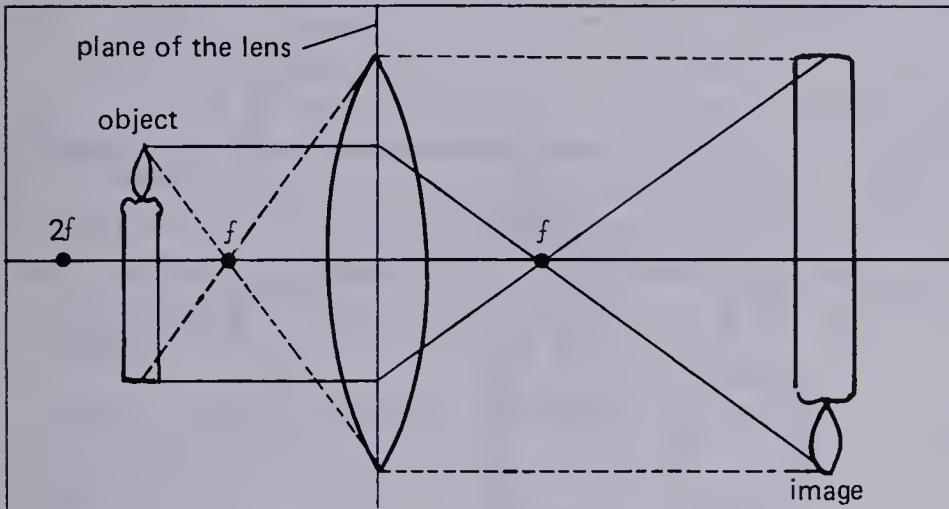


Figure 10-4

1. Draw lines from the ends of the object perpendicular to the plane of the lens. From where they meet the lens, draw through the other principal focus.

2. Draw lines from the ends of the object through the principal focus to where they meet the plane of the lens. Then continue them from these points perpendicular to the plane of the lens.

3. Where the lines come together locates the image.

- ★ 10-16. Here's a challenge for you. Predict what image will result if you place a small object at exactly the focal point of a lens. (Hint: Use the two rules for finding an image.)

With the object at f , notice how the two rules you have studied will apply. Rule 1 works well enough. Look at Figure 10-5 below. Parallel rays (from different object points) will cross at the f on the other side of the lens. But Rule 2 shows what's strange. Since each point on the object is already at the focal distance, rays drawn from any object point through the focal point f will go straight up or down. They can never pass through the lens. And they can never meet to form an image point.

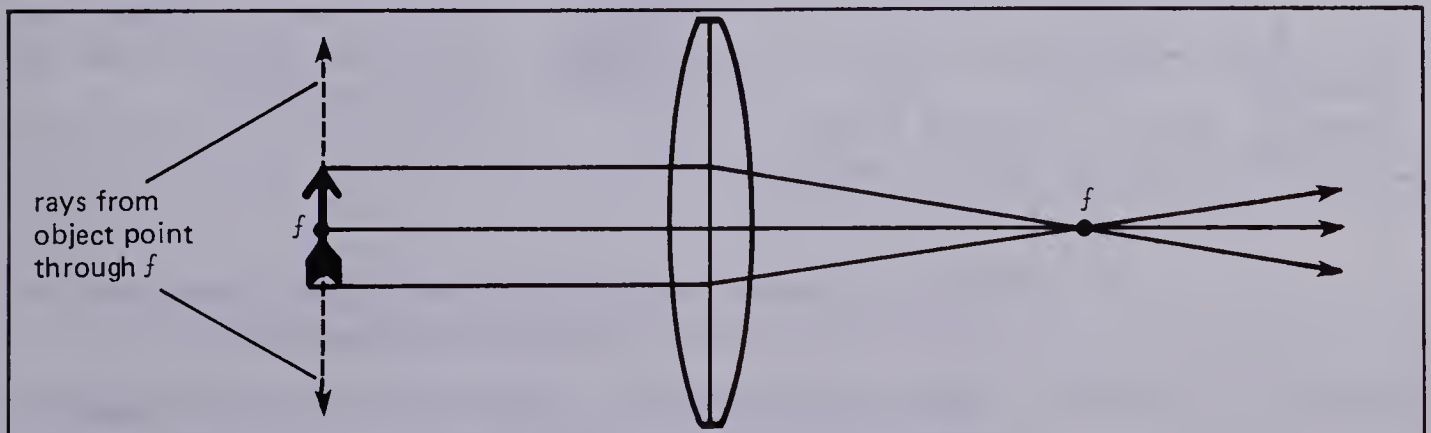


Figure 10-5

What happens if the object is between f and the lens? Let's see if a ray diagram can help you predict this. Look at Figure 10-6 below. The object — candle flame — is between f and the lens. (To avoid too many confusing lines, rays from the tip of the flame only will be shown.)

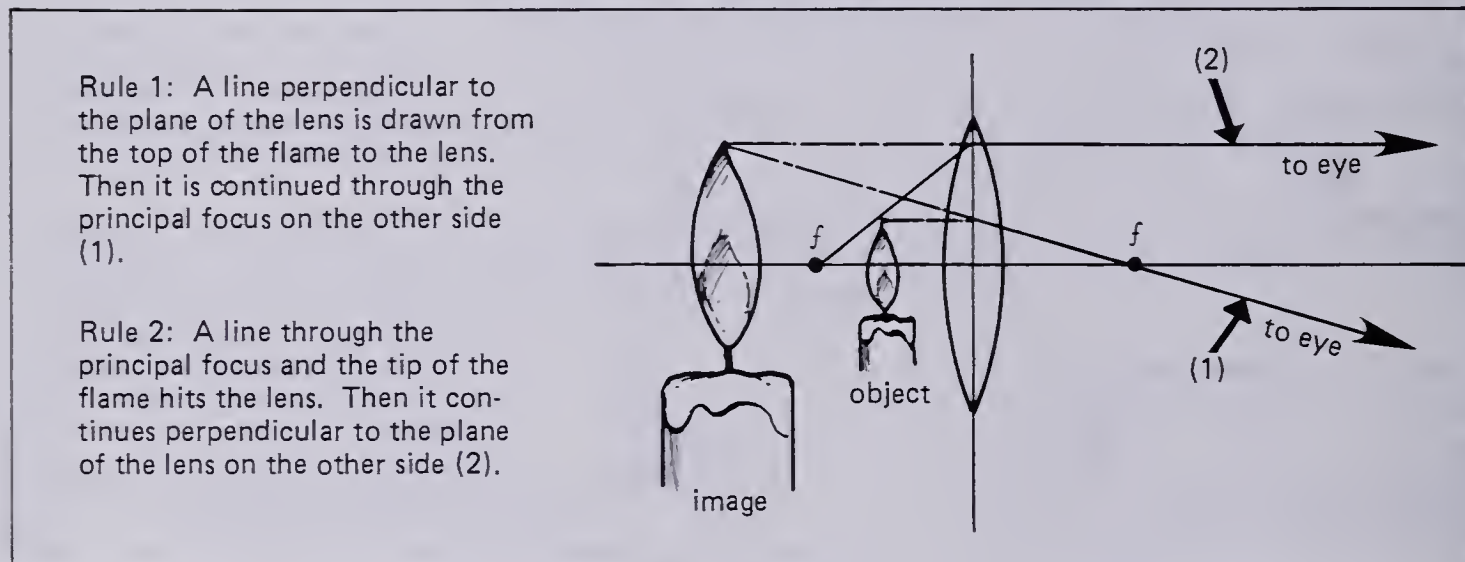
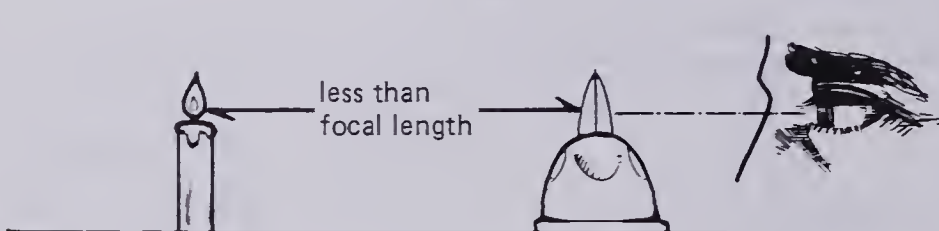


Figure 10-6

- 10-17. Will the two rays ever cross on the other side of the lens?

The rays won't cross on the other side. But if they are extended back through the lens (the dashed lines), they will cross on the same side of the lens as the object. To an eye on the right, the rays will appear to come from an image of the candle flame. When an image only appears to be formed instead of actually being formed by rays coming together, it is called a *virtual image*. You can observe a virtual image.



F. Place the lighted candle closer than f to either convex lens. Look through the lens at the flame.

- ★ 10-18. Describe the image when the object is closer than f to a convex lens, in terms of size, appearance, and location.

No matter how hard you try, you can't focus an image on a screen when the object is closer than f . A virtual image cannot be focused on a screen. Try it if you wish.

ACTIVITY 11: ILLUMINATION

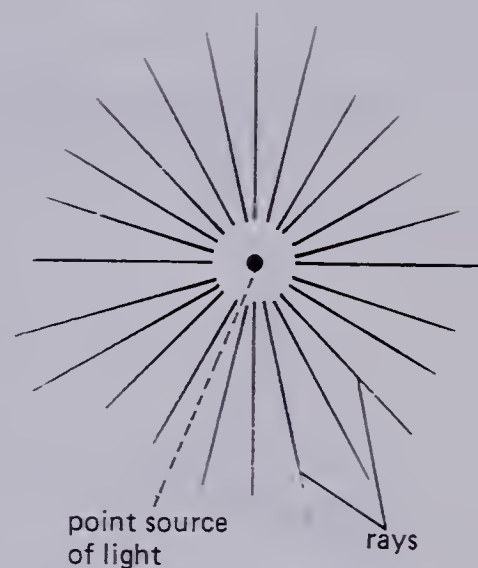
Assuming both are lit, a 100-watt light is much brighter than a birthday candle. And the bulb is certainly a better light source for reading. But suppose the candle is in your hand and the light bulb is 100 metres away.

Absolute brightness is one thing. Illumination is something else. One of the very bright objects in the universe is Rigel [RYE-jul], a star in the constellation of Orion. Its luminosity is 50,000 times greater than the sun's. But as a source of Earthly illumination, Rigel is no use. A firefly can provide more light.

To understand this, return to the ray model of light. Use it in making the following investigation. You'll need the following materials.

4 pieces of string or thread, 120 cm each
support stand
masking tape
metre stick
metric ruler
paper, cardboard, or plywood, 20-cm square

You'll also need a flat-top table or desk in a suitable location. Find a place where the table can hold the stand one metre from a flat, vertical surface, such as a wall, chalkboard, or window.



A. In your notebook, make a table similar to this one. You'll begin using it at Step E.

POSITION	DISTANCE FROM SOURCE	DISTANCE RATIO	WIDTH	HEIGHT	AREA	AREA RATIO
A	25 cm	1				1
B	50 cm	2				
C	75 cm	3				
D	100 cm	4				

B. Set the stand on the table. Fasten the four strings to the upright at a convenient level.

C. Locate and mark the center of the 20-cm square. Then use the masking tape to mount the square on the wall, chalkboard, or window. Have two sides horizontal. Make sure the center is at the same height as the strings that are fastened on the support stand.

D. Place the support stand one metre from the square on the wall. Then tape the other ends of the strings to the four corners of the square. The strings should be stretched tight.

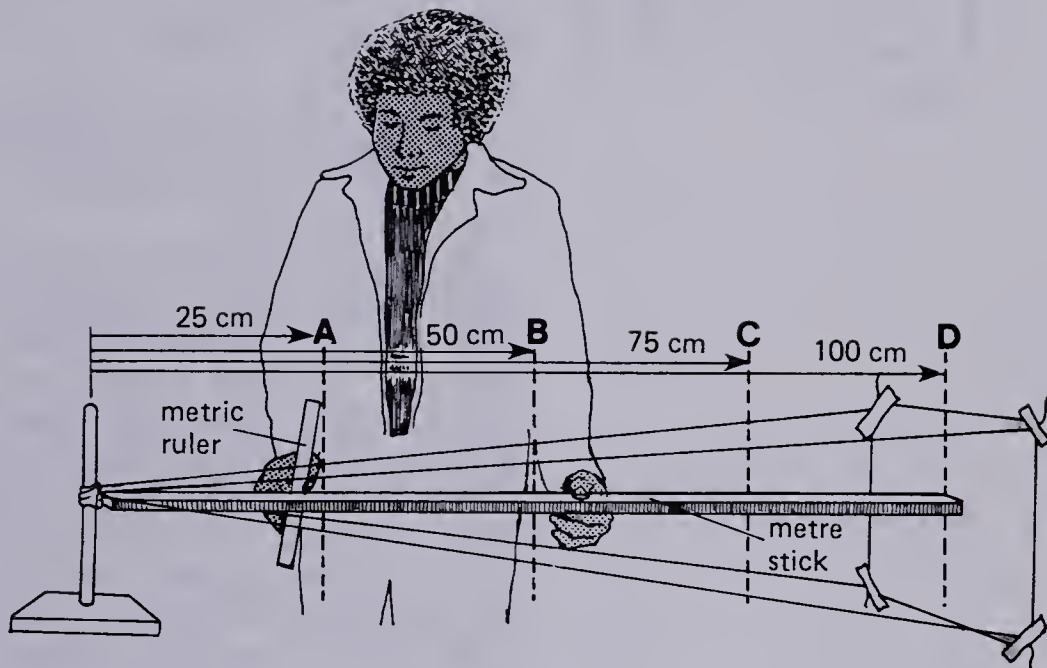
- 11-1. Suppose that Point L in Step D represents a point source of light. What do the four stretched strings represent?

Light goes out from the point source in all directions. As it does, the light rays get farther and farther apart. That means the light is being spread out more and more. To see how much it spreads, continue the investigation.

For the next step you may need a partner's help. Try it on your own. Then, if necessary, get a partner and try again.

E. Hold the metre stick between the "light source" and the square on the wall, as shown. Find the point on the metre stick that is 25 cm from the light source (Position A in the diagram). Then, to the nearest cm, measure the distance between the top two strings at this point. Enter this figure in the top line of your table under "Width." Then measure the vertical distance between two strings at Position A. Enter this figure in the first line under "Height."

F. Repeat Step E at the other marked distances — 50 cm (Position B), 75 cm (Position C), and 100 cm (Position D). Enter the measurements to the nearest cm in the table.



Use the data to fill in the "Area" column in your table. The area is the width times the height. The same amount of light passes through these increasingly larger areas as it travels away from the source.

Look in your table at the column headed "Distance Ratio." You measured distances in units of 25 cm each. At Position B, you measured 50 cm, which is two of these units — 25 cm from the light source to Position A and another 25 cm from Position A to Position B.

- 11-2. Explain the meaning of the 3 for Position C in the "Distance Ratio" column of your table.

Now look at the "Area Ratio" column of your table. Determine how many times greater the area was at Position B than at Position A. Enter the result in the table. Do the same for Positions C and D, comparing their areas, in turn, with that of Position A.

- 11-3. Do the area ratios increase by the same amounts as the distance ratios?

DISTANCE RATIO	AREA RATIO
1	1
2	4
3	9
4	16

Figure 11-1

If you did everything right, the two ratio columns should look like Figure 11-1.

- 11-4. Look carefully at the horizontal pairs of values in the ratio columns of Figure 11-1. How are the members of each pair related?

The area ratios are exactly the squares of the distance ratios — $1^2 = 1$, $2^2 = 4$, $3^2 = 9$, and $4^2 = 16$. Now let's see what all that has to do with light.

Remember that Point L — where the strings are tied together at the support stand — represents a point source of light. Suppose this point source is sending out light toward the paper square. The same amount will go through the square at Position A, then at Position B, then at Position C. And it will arrive at the paper square at Position D.

You have used the same light source for all positions along the rays. Therefore, the amount of light going through each position in one second will be the same for every position. However, the same amount of light will be spread out more and more.

See what this means in Figure 11-2 below. One square unit of surface at B will receive only one-fourth the amount of light received by the surface at A.

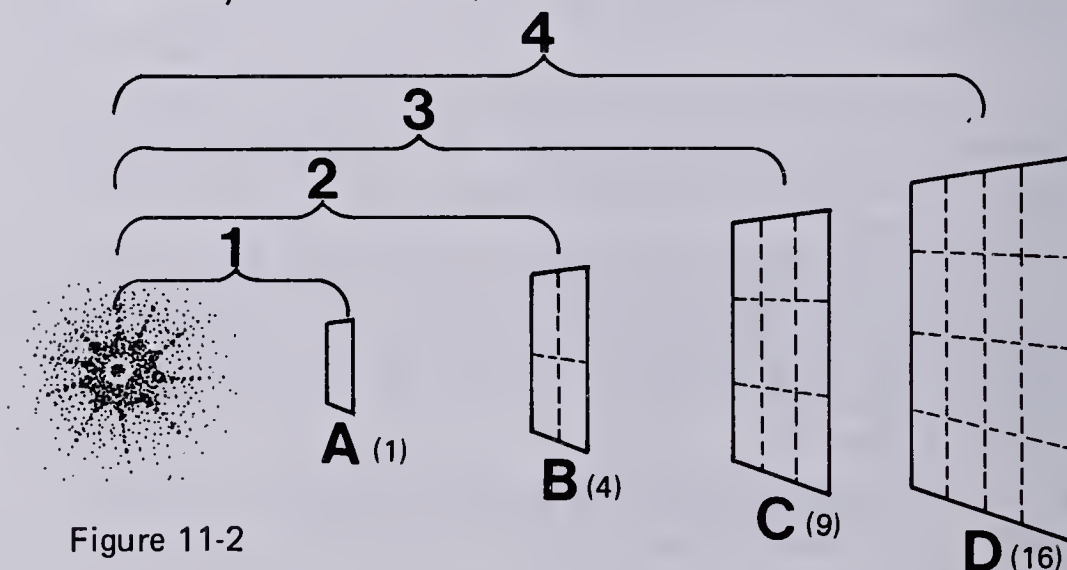


Figure 11-2

- 11-5. Relative to the surface at A, how much light does one square unit of surface at C receive?

The amount of light received over a given area of surface is called the *illuminance* of that surface. As you have seen, the illuminance from a given light source depends upon the distance of the surface from the source. The square relation that you found earlier is often stated as a law.

Law: The illuminance of a surface is inversely proportional to the square of its distance from the source of light.

Inversely proportional to the square means, for instance, that doubling the distance from the light source will cut the illuminance on the surface to one-fourth. And, put the other way around, if the distance is cut in half, the illuminance will be four times greater.

★ 11-6. If an object is moved to four times its original distance from a light source, how will the illuminance on the object change?

But, of course, if Rigel and the birthday candle are the same distance from a surface, Rigel will provide more illuminance. The intensity of the light source — its brightness, roughly speaking — is also important.

Luminous intensity is measured in *candela* [kan-DEL-a]. The candela (cd) is a basic unit in scientific measurement like the metre, kilogram, and second. All other light units are derivable from it, including the lumen (lm) — the unit of light quantity or luminous flux — and the lux (lx) — the unit of illuminance. Look at Figure 11-3 below.

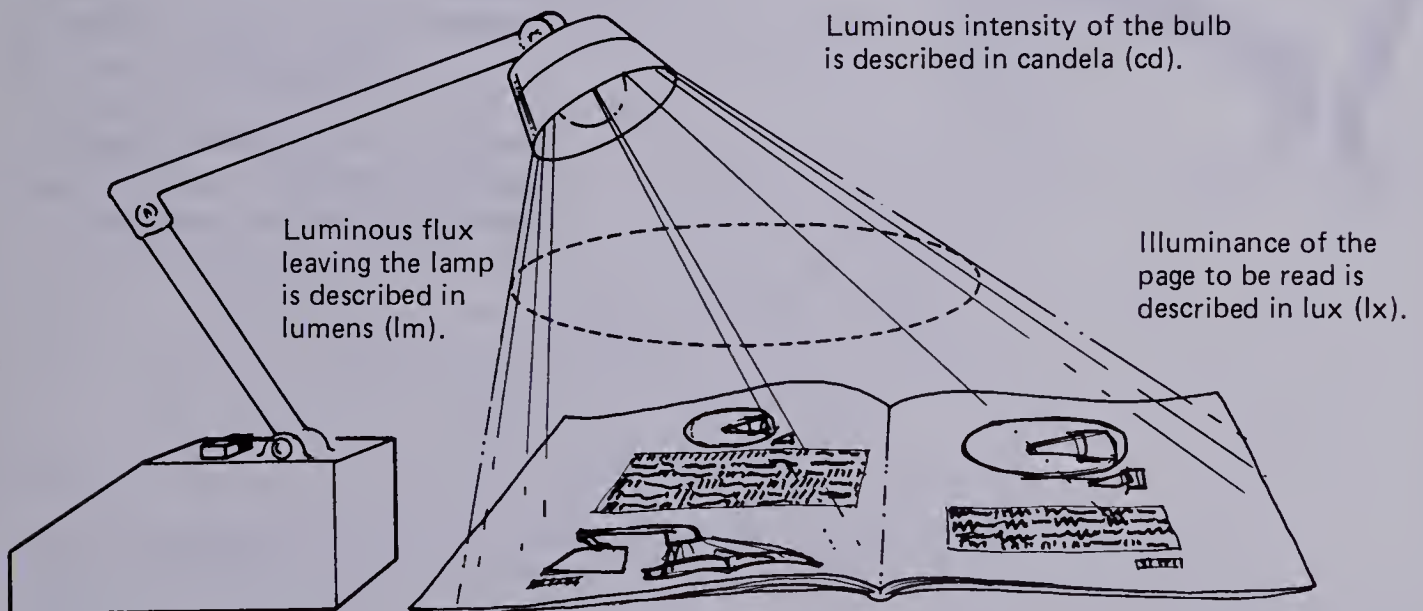


Figure 11-3

★ 11-7. What is the unit for measuring each of the following?

- A. Intensity of light source (luminous intensity)
- B. Quantity of light (luminous flux)
- C. Illumination (illuminance)



ACTIVITY 12: PLANNING

Activity 13

Page 69

Sunglasses

Sunglasses are not all alike. After reading this activity, you may think twice before buying just any sunglasses at the drugstore. You'll want sunglasses that can do the best job for you.

Activity 14

Page 74

The Blind Spot

Everyone is a little bit blind. In fact, you have two blind spots — one in each eye. In this activity, you can locate them.

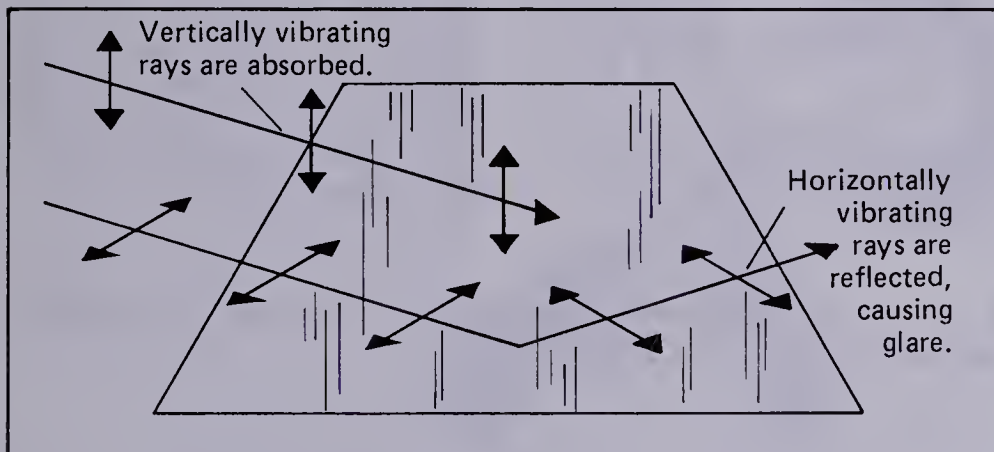
ACTIVITY 13: SUNGLASSES

Bright light makes people squint. The glare off water or the hood of a car can be very disturbing. The solution for the problem may be sunglasses.



Most sunglasses fall into one of two types — those that are simply tinted and those that are polarized as well. Tinting just cuts down on the amount of light getting to the eyes. Polarizing screens out part of the light in a selective way.

Think of light rays as waves vibrating in all directions. When the rays hit shiny horizontal surfaces, such as a lake or wet road, most of the rays vibrating at or near the vertical are absorbed. The more horizontal rays are reflected. Because of this, most glare is rays vibrating in a horizontal plane.

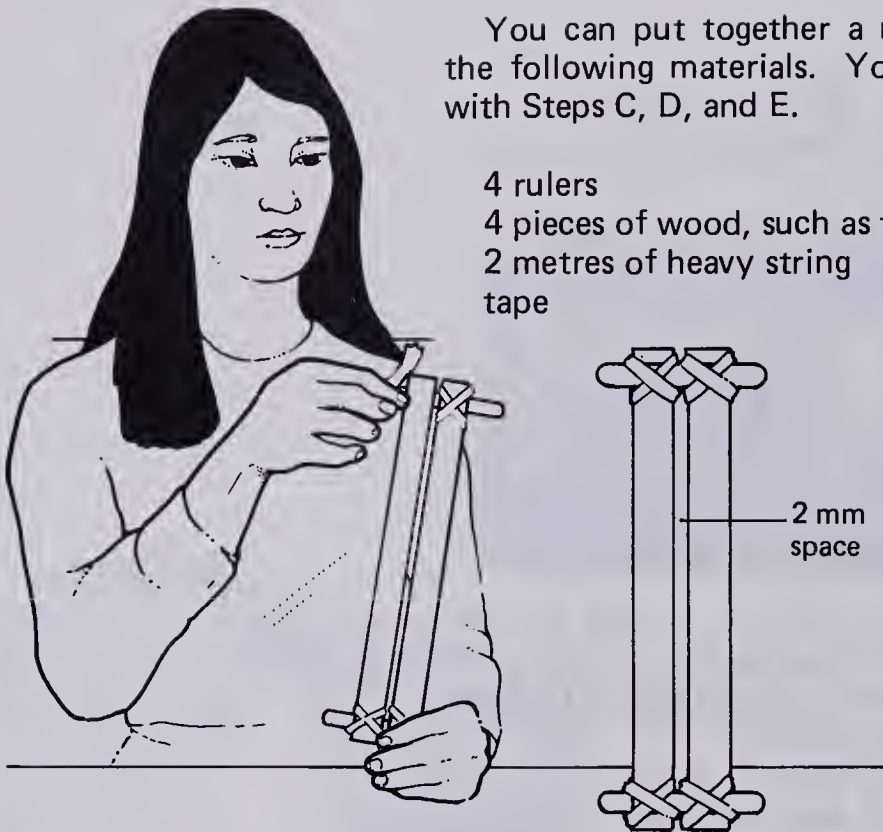


- 13-1. Suppose light is being reflected from a highway surface after a light rain. Which way are most of the light waves vibrating?

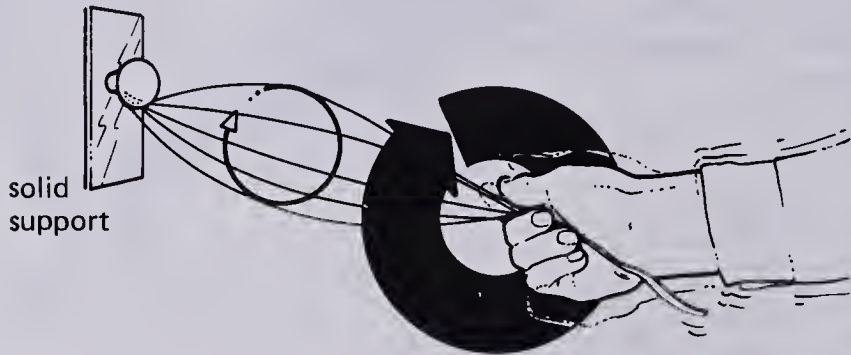
Some people are confused by the terms *horizontal* and *vertical*. For purposes of this activity, think of horizontal light waves as zigzagging back and forth in a direction parallel to Earth. Vertical waves zigzag up and down like waves in the ocean.

You can put together a model of vibrating light waves. Get the following materials. You'll also need a partner to help you with Steps C, D, and E.

4 rulers
4 pieces of wood, such as tongue depressors
2 metres of heavy string
tape

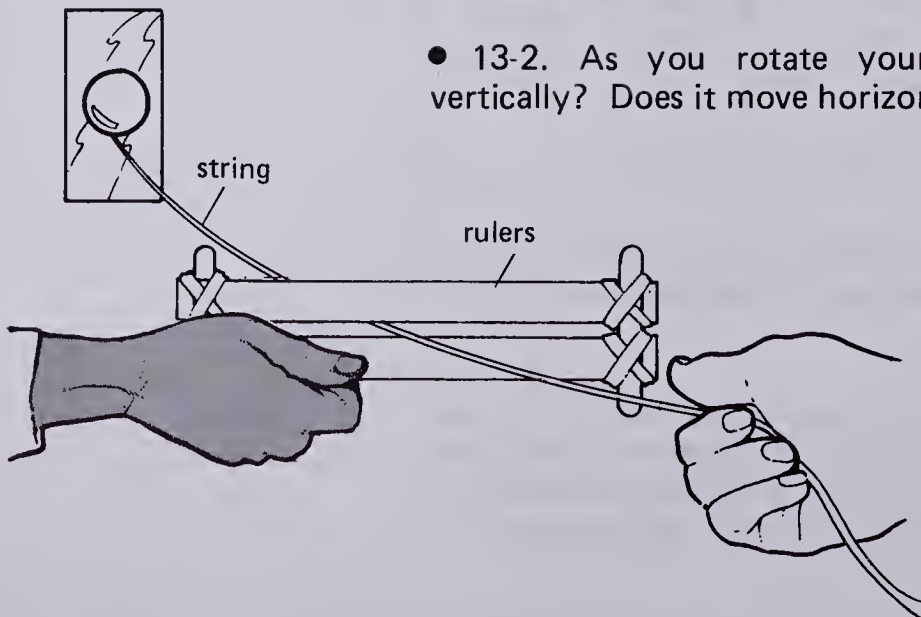


A. Use tape to fasten two of the rulers to two of the pieces of wood. Leave a 2-mm space between the rulers. The wood pieces should be at the ends of the rulers, as shown. Then repeat the procedure with the other rulers and pieces of wood.



B. Tie one end of the 2-m string to a solid support — a doorknob, perhaps, or the handle of a file cabinet. With some slack in the string in your hand, move your hand in a circle, as shown.

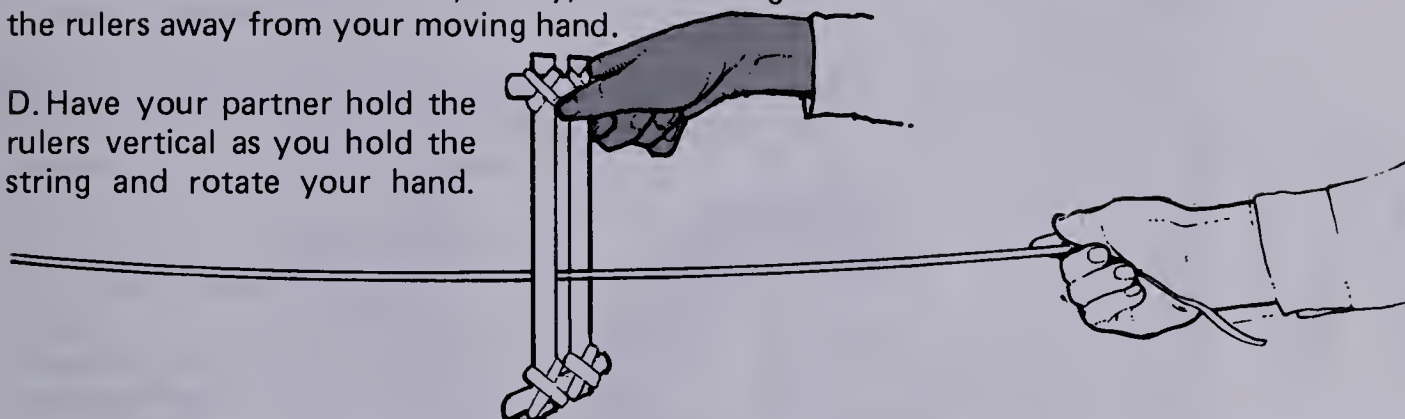
• 13-2. As you rotate your hand, does the string move vertically? Does it move horizontally?



C. Thread the string through the space between one set of rulers. Have your partner hold the rulers horizontal, about in the middle of the string. Again, rotate your hand, holding the end of the string.

- 13-3. Describe the motion, if any, of the string on the side of the rulers away from your moving hand.

D. Have your partner hold the rulers vertical as you hold the string and rotate your hand.

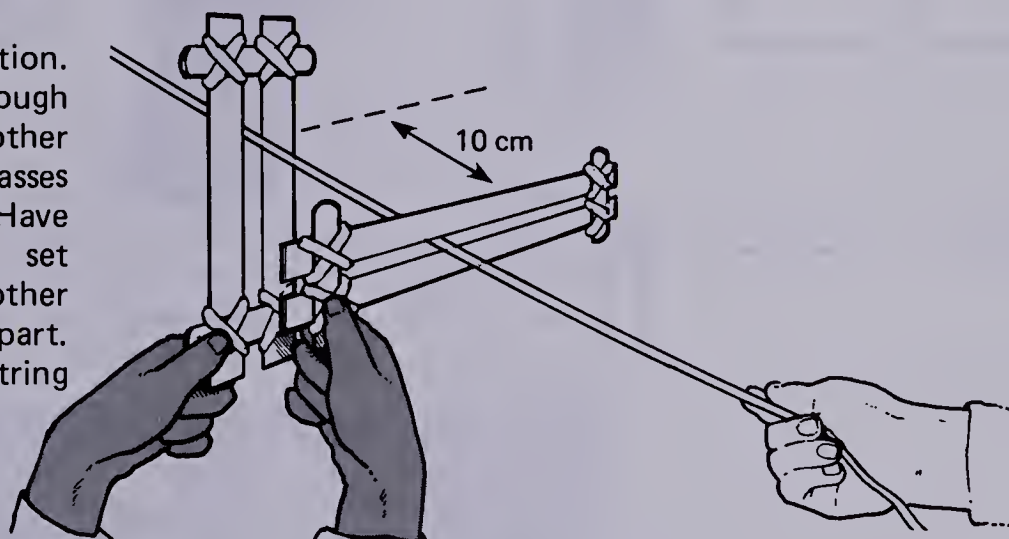


- 13-4. Describe the motion, if any, of the string on the side of the rulers away from your moving hand.

- 13-5. If the vibrating string represents a light wave, which positioning of the rulers lets you represent the glare of a horizontal surface?

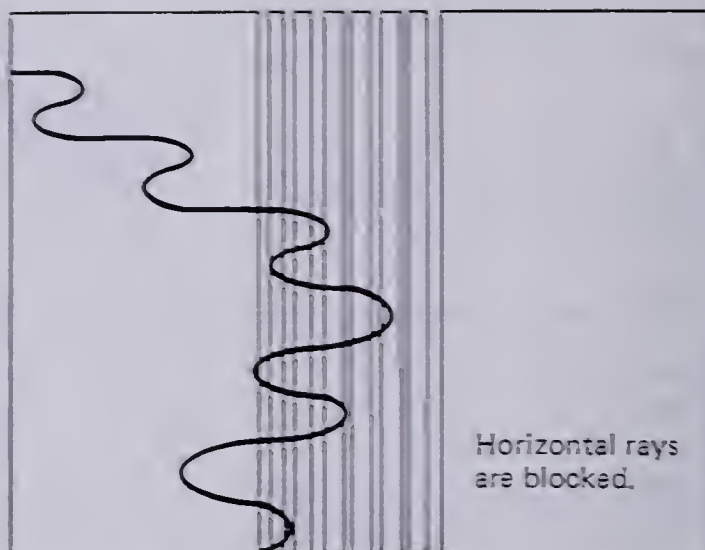
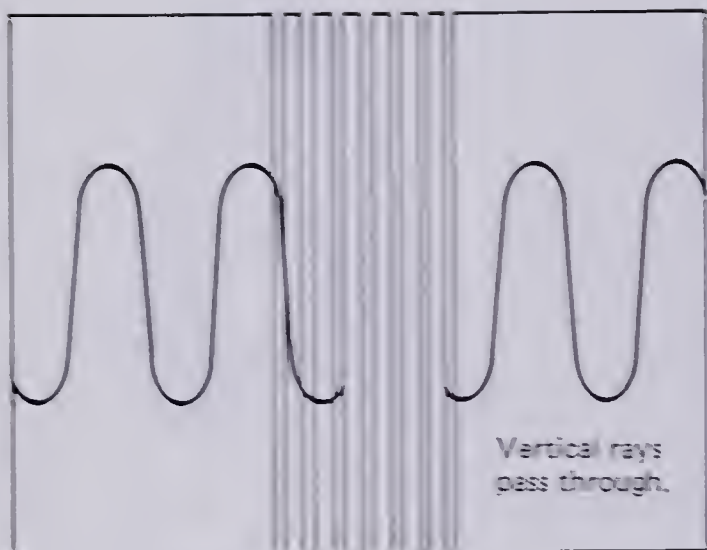
- 13-6. Suppose rulers are held both horizontally and vertically. What do you predict about the motion of the string beyond both rulers?

E. Test your prediction. Thread the string through the space between the other set of rulers, so that it passes through both sets. Have your partner hold one set horizontally and the other vertically about 10 cm apart. Rotate the end of the string in your hand.

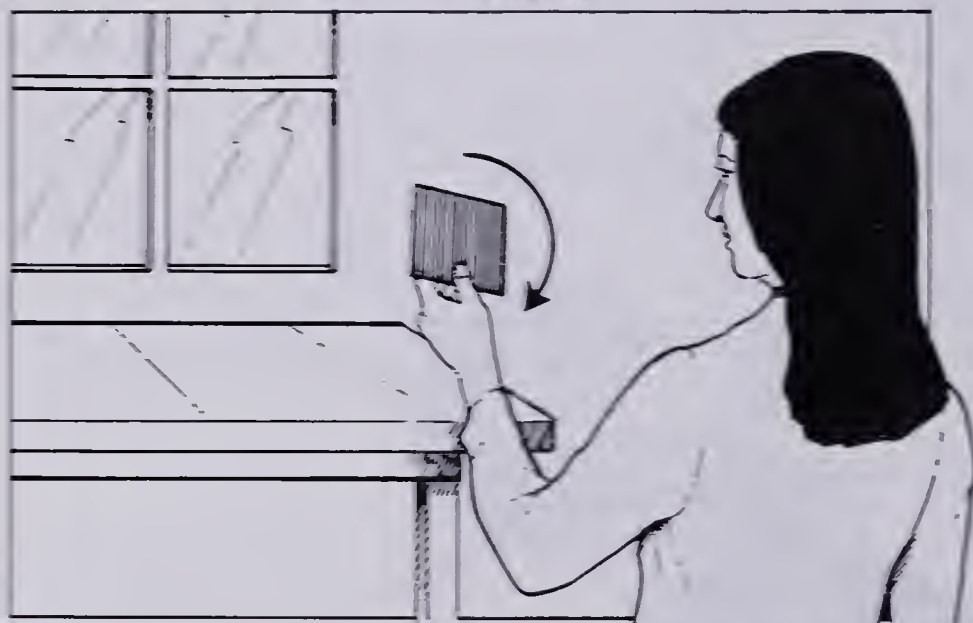


- 13-7. How does your observation agree with your prediction for Question 13-6 above?

Some sunglasses are made of light-polarizing material. This was first made in plastic-sheet form in 1932. The polarized material is composed of slender crystals lined up in a particular direction. These crystals act for light as the pair of rulers did for the string. They can, for example, allow light rays with vertical vibrations to pass through but block rays with horizontal vibrations. In this way, they cut down on glare.

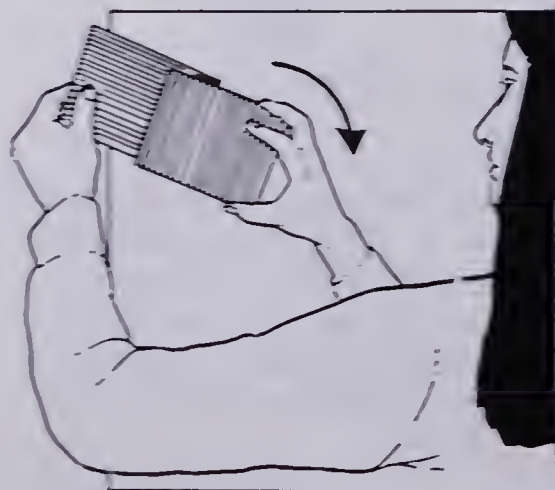


Check this out for yourself. Get two pieces of polarizing material.



A. Using one piece of the material, look at light reflecting off a horizontal surface. Slowly rotate the polarizing material to see whether that makes any difference.

• 13-8. Describe your observations.

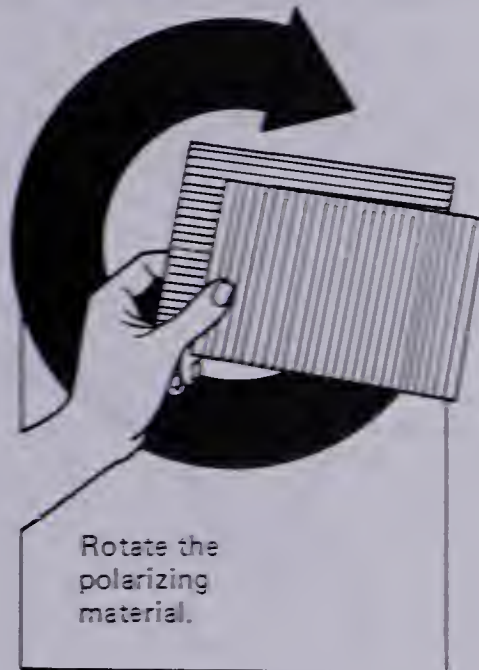


B. Look through both pieces of polarizing material at the same time. Rotate one piece, and see what happens.

☆ 13-9. Explain how and why two polarized lenses can be arranged to block out most light.

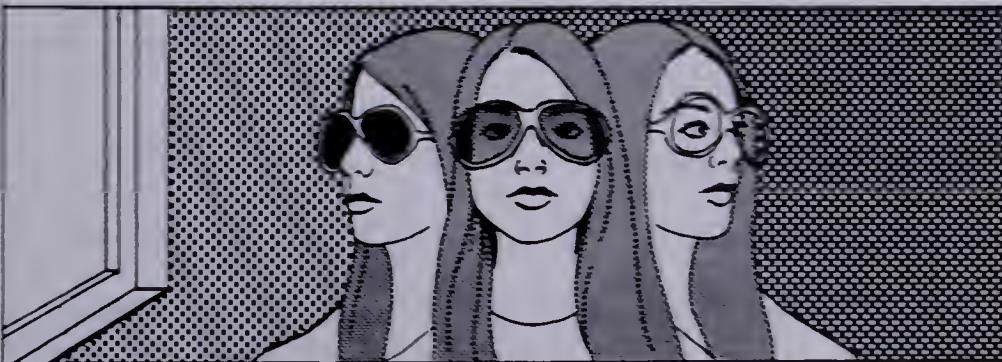
☆ 13-10. Do you think polarized sunglasses will work well for reducing vertical glare from a window pane? Explain your answer.

C. Try one more test. Adjust the two pieces of polarizing material so that light is blocked out when you look through them. Then rotate them together, and continue to look through them.



● 13-11. What happened?

In the late 1960s, a new type of sunglasses was introduced. These sunglasses have light-sensitive lenses that automatically darken when exposed to ultraviolet light. Sunlight contains both visible and ultraviolet wavelengths. In dim light, or inside when very little ultraviolet is present, the coloring in the lenses almost disappears. They look much like regular glass. These glasses can be comfortably worn both indoors and out. Light-sensitive lenses can also be ground to fit individual eyeglass prescriptions.



● 13-12. An artist complained that her new light-sensitive glasses sometimes made everything too dark indoors. Describe what might be causing the problem.

ACTIVITY 14: THE BLIND SPOT

Activity 2 may have made you think that the retina — the curved back surface of the eye — is entirely covered with light-sensitive cells. That's not quite the case. The nerve fibers connecting the light receptor cells to the brain all come together in the optic nerve. Where the optic nerve leaves the retina, there are no light-sensitive cells. This area — about the size of a pin-head (less than 0.2 mm across) — is known as the *blind spot*. Figure 14-1 below shows a cross-sectional view of the right eye from above.

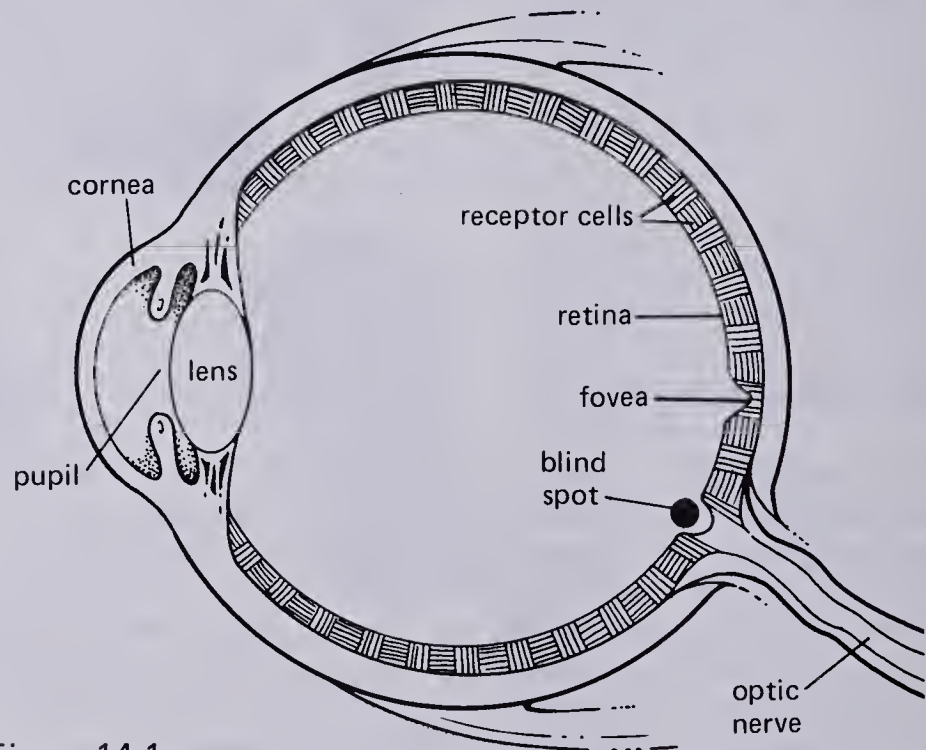
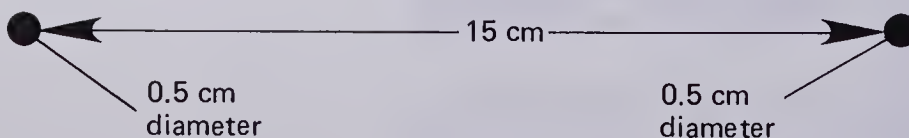


Figure 14-1

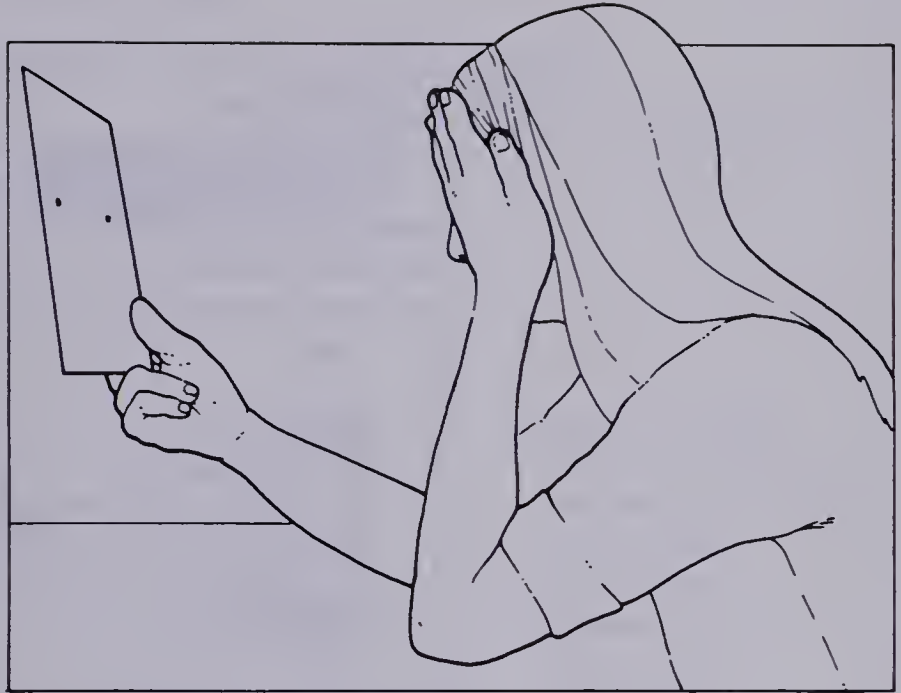
You can locate the blind spot in each of your eyes. You'll need the following materials.

sheet of white paper
pencil or pen
metric ruler



A. Mark off two points about 15 cm apart on the sheet of paper. Then turn the points into dark spots about 0.5 cm in diameter.

B. Hold the paper in your right hand about a ruler's length (30 cm) from your face. Hold your left hand over your left eye. With your uncovered right eye, stare straight at the left-hand spot. Slowly move the paper away from your face until something happens to the right-hand spot.



- 14-1. What happens to the right-hand spot?

C. Now hold the paper in your left hand. Cover your right eye with your right hand. With your left eye, stare at the right-hand spot as you slowly move the paper away.



- 14-2. What happens to the left-hand spot?

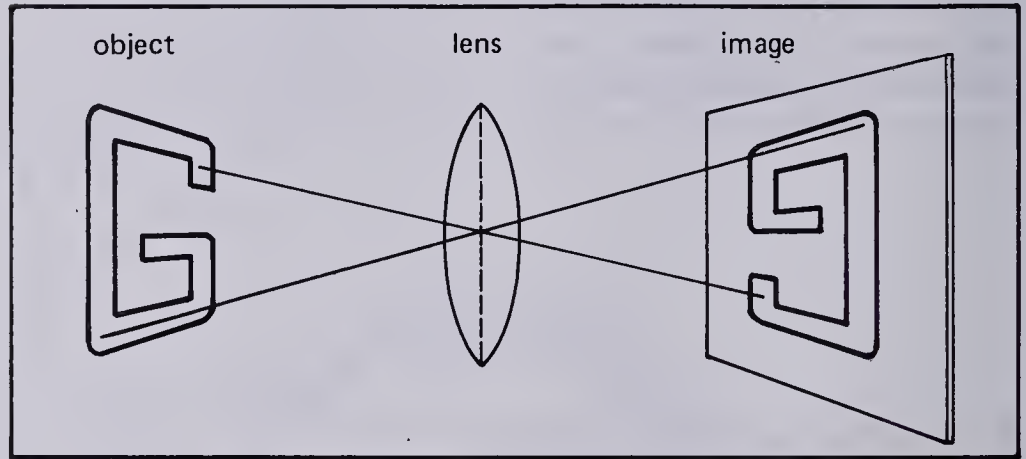
★ 14-3. What do you think causes the blind spot in each eye?

The fact that the outside spot disappears with each eye should give you a clue to the next question.

- 14-4. There's a blind spot in each eye. Where is it located on the retina — toward the outside of the eye, or toward the inside (toward the nose)?

You can answer Question 14-4 (page 75) if you remember the following clues.

1. The lenses in your eyes are convex.
2. A convex lens turns the real image of an object upside down. When an object is turned that way, right becomes left, and left becomes right.



3. When you found the blind spots in Steps B and C, it was the outside dark spot that disappeared.

Here's a tough question. You may not know the answer, but try it anyway.

- 14-5. Why don't you always notice your blind spots? Shouldn't they show up as black places in your field of vision? (Hint: You have two eyes.)

PERSONNEL

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